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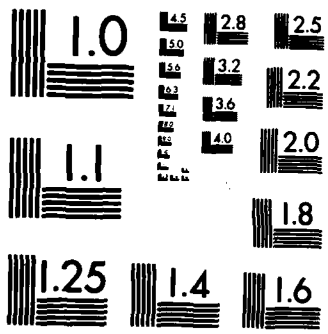

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The transport of dissolved and particulate nutrients, metals, and organic material from watershed to lake plays a dominant role in determining lake water quality. For lakes which receive a majority of their loads from a single, large tributary, processes occurring in headwater areas may act to modify the ultimate impacts of these loads. These processes include sedimentation, phytoplankton production, microbial degradation, and

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ABSTRACT (Continued).

oxidation-reduction reactions. This will be particularly true in stratified lakes and reservoirs which exhibit density currents.

Studies conducted at West Point Lake, Georgia, during October 1980 and July 1981 employed tracer dye to allow repetitive sampling of parcels of inflowing Chattahoochee River water as they entered and progressed through the upstream portion of the reservoir. Inflows during October 1980 were vertically well mixed, while those in July 1981 entered as an interflow. A well-defined plunge point was observed in the lake's headwater area during the July 1981 study.

Time-related changes in suspended solids, chlorophyll, nutrient, and metal concentration were observed. Changes in dissolved oxygen during the July 1981 study resulted from a reduction in photosynthetic productivity and the confinement of river water to intermediate depths. Increases in manganese concentration and dye distribution suggested the entrainment of hypolimnetic water by the riverine layer and the mixing of riverine water into the epilimnion.

PREFACE

The work described in this report is part of the Environmental and Water Quality Operational Studies (EWQOS) Work Unit VIIA, Reservoir Field Studies, conducted by the U. S. Army Engineer Waterways Experiment Station (WES) for the Office, Chief of Engineers (OCE), U. S. Army. The OCE Technical Monitors were Mr. Earl Eiker, Mr. John Bushman, and Mr. James L. Gottesman.

The study was completed by the Aquatic Processes and Effects Group (APEG), Environmental Research and Simulation Division (ERSD), Environmental Laboratory (EL), WES. The report was prepared by Dr. Robert H. Kennedy, Mr. Robert C. Gunkel, Jr., and Ms. Janice V. Carlile, APEG, under the supervision of Dr. Thomas Hart, Chief, APEG, Mr. Donald L. Robey, Chief, ERSD, and Dr. John Harrison, Chief, EL. Dr. Jerome L. Mahloch was Program Manager of EWQOS.

Commander and Director of WES during the study and preparation of this report was COL Tilford C. Creel, CE. Technical Director was Mr. F. R. Brown.

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RIVERINE INFLUENCES ON THE WATER QUALITY CHARACTERISTICS OF WEST POINT LAKE

PART I: INTRODUCTION

Background

1. The transport of material from watershed to lake is a dominant mechanism affecting lake water quality since these inputs represent a major source of nutrients and organic material. When nutrient and organic inputs are excessive, the lake often exhibits symptoms of eutrophication. These symptoms include algal blooms, odors, hypolimnetic oxygen depletion, and reduced transparency.

2. The effects of interactions between watershed and lake are often pronounced in artificial impoundments. Unlike most small natural lakes, reservoirs are located at the downstream boundary of proportionately larger watersheds and inputs often occur via a single large tributary. A significantly larger drainage-area-to-surface-area ratio suggests higher nutrient, water, and suspended loads for reservoirs than for natural lakes (Thornton et al. 1981). The distribution of influent materials within the lake is affected by lake morphology and hydrodynamics. Since many reservoirs are long and narrow, the entrance of a large tributary at a location distant from the lake's discharge often results in the establishment of longitudinal patterns in water quality (e.g., Kennedy, Thornton, and Carroll 1981; Thornton et al. 1982; Peters 1979) and sediment characteristics (e.g., To and Randall 1975; Gunkel et al. 1983). The reduction in suspended solids by sedimentation as inflows enter the wider and deeper lake basin results in increased water clarity. Nutrient, organic, and metal concentrations also decline, due in part to their association with sedimenting particulates. Graded responses in zooplankton (Zurek 1980) and phytoplankton (Kennedy, Thornton, and Gunkel 1982; Cherry et al. 1980) also occur from headwater to dam.

3. The occurrence of density flows in stratified lakes and

reservoirs also influences the fate of influent materials (e.g. Carmack et al. 1979; Gloss, Mayer, and Kidd 1980). During periods of thermal stratification, riverine water may, depending on its density, enter the lake as an overflow, interflow, or underflow (Ford and Johnson 1983). The confinement of riverine water as an interflow or underflow may reduce the impact of nutrient and suspended loads on the epilimnion and/or result in significant changes in the quality of the influent water. Therefore, the occurrence of density flows may greatly alter the impacts of material inputs from the watershed.

Purpose and Scope

4. Inflow-related patterns in water quality, which have been documented for several reservoirs (Thornton et al. 1982; Kennedy, Thornton, and Gunkel 1982; Kennedy, Thornton, and Carroll 1981) and river-fed lakes (Peters 1979) prompted Thornton et al. (1981) to suggest an heuristic model describing longitudinal patterns in water quality. Proposed in the model is the existence of three zones: a riverlike zone, a lakelike zone, and an intermediate zone exhibiting characteristics of both river and lake. While these zones are dynamic in nature, water quality conditions exhibited by each reflect the influence of flow and hydrodynamics, sedimentation, and other inflow-related processes. The study reported herein was designed to determine the effects of inflow-related processes on the quality of river water entering a large hydropower reservoir under differing inflow regimes. The potential effects of these processes on the establishment of longitudinal patterns in water quality in this and other reservoirs are discussed.

PART II: STUDY SITE

5. West Point Lake is a large hydropower reservoir created in 1974-75 by impoundment of the Chattahoochee River 80 km downstream from the city of Atlanta in west-central Georgia (Figure 1). The Chattahoochee River, which arises in the Blue Ridge Mountains of northeast Georgia and is initially impounded by Bufford Dam, flows southwest through the Piedmont Physiographic Province to West Point Lake and then south to its confluence with the Flint River to form the Apalachicola River. The water quality of the river above West Point Lake reflects the influence of geology and land use. Soils of the Piedmont Province consist primarily of red clays (Wharton 1977) which are easily eroded from cultivated fields and transported by tributary streams. This results in the

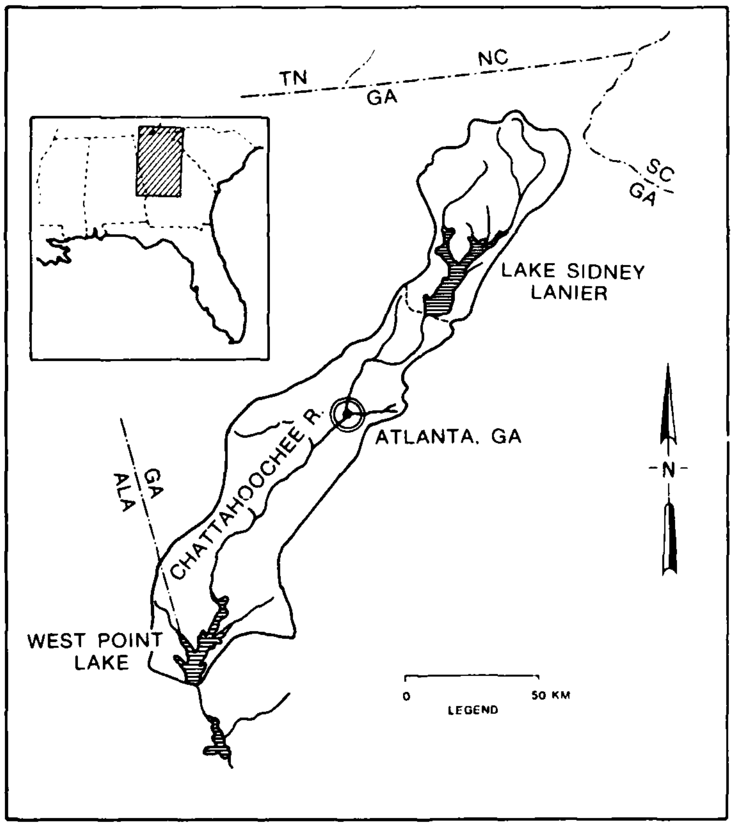

Figure 1. Location of West Point Lake and its watershed

characteristically turbid, reddish-brown appearance of the river. Discharges from numerous waste treatment facilities, and other point and nonpoint sources along the 190-km reach above West Point Lake, particularly in the Atlanta metropolitan area, markedly increase nutrient and organic loads transported by the river.

6. Other tributaries to the lake include New River, Yellowjacket Creek, and Wehadkee Creek (Figure 2), which, when combined, supply approximately 5 to 6 percent of the annual water income. Land uses in basins drained by these tributaries range from predominately forest and pasture (New River and Wehadkee Creek) to urban and industrial (Yellowjacket Creek). Impoundment of the river has inundated the floodplains

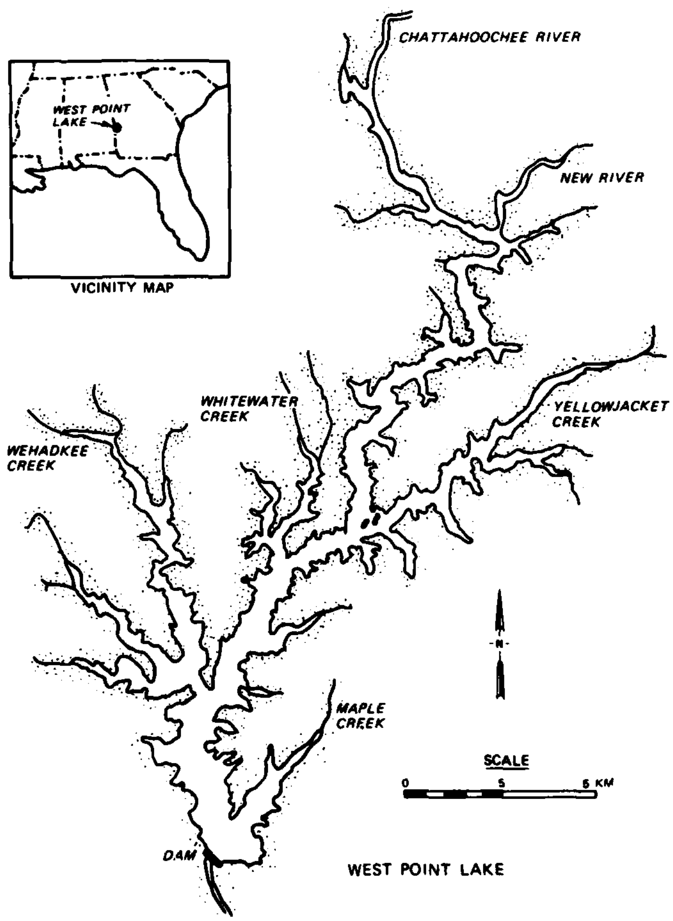

Figure 2. West Point Lake and its major tributaries

of both Wehadkee and Yellowjacket Creeks resulting in the formation of relatively large embayments along the west and east shore, respectively.

7. West Point Lake (Figure 2) is a long (53 km), narrow, and dendritic (shoreline development ratio of 23) lake with mean and maximum depths of 7.1 and 31.0 m, respectively (at pool elevation 193.6 m mean sea level (msl)). Other limnological characteristics are presented in Table 1. Pool elevations, which fluctuate daily and seasonally in response to power generation and flow conditions, respectively, normally range from 190.5 (winter) to 193.6 (summer) m msl. Daily fluctuations, when they occur, are slight.

8. Releases for power generation occur through bottom gates while additional releases occur periodically from the epilimnion through a gated spillway. However, the remnants of a cofferdam built during construction act as a skimming weir forcing primarily epilimnetic and metalimnetic water to be discharged during power generation (Kennedy, unpublished data).

9. The lake is characterized by high nutrient and suspended solid concentrations, anoxic bottom water, and frequent algal blooms. Staining of the tailwater and hydrogen sulfide odors during releases are also frequently occurring water quality problems. While high sedimentation is suspected, there exist no data to quantify accumulation rates or the relative distribution of sedimented material.

10. Flow from the Chattahoochee River, because of the narrowness of the lake's basin, exerts a significant effect on conditions in the lake (Kennedy, Thornton, and Gunkel 1982). Riverine flows are observed in he ;ater areas and, during periods of high flow, as far downlake as the confluence of Yellowjacket Creek. Coincident with these flows are high suspended solid, nutrient, and organic concentrations. As flow velocities decrease downlake, water clarity increases resulting in high algal production at mid-lake. Gradients in nutrient concentrations are also observed. Changes in the location of the plunge point, or the location at which inflowing water sinks to a depth of similar density, are also coupled with changes in flow. The location of the plunge point, which has been observed to occur along the reach between New River and

Yellowjacket Creek, is often clearly defined as a region of abruptly decreasing turbidity or by debris accumulation. Conditions below the plunge point, and in broader, downlake areas are more lakelike. However, zones of highly turbid water at intermediate depths are frequently observed downlake from the plunge point. During nonstratified periods, inflows appear to be well mixed vertically.

11. West Point is a warm monomictic lake exhibiting weak thermal stratification during summer months. Hypolimnetic anoxia occurs in Yellowjacket and Wehadkee Creek embayments and in the lower half of the lake's major basin. Partial impoundment of hypolimnetic water behind the cofferdam, as mentioned above, may influence the severity of oxygen depletion by increasing the detention time of hypolimnetic water.

12. In addition to power generation and flood control, the lake also offers a strong sport and commercial fishery (Davies et al. 1979) and extensive recreational facilities. Lakeside residential development, however, is limited to a relatively small, isolated area along Yellowjacket Creek embayment. The lake also serves as a municipal and industrial water supply.

PART III: METHODS

Water Tracing

13. Injection of Rhodamine WT (Crompton and Knowles, Skokie, Ill.), a commonly employed tracer dye (e.g. Johnson 1983), provided a means by which a single parcel of river water could be located and repeatedly sampled as it entered and progressed through the upper portion of the lake. Although recent evidence suggests potentially hazardous effects resulting from its use in nitrate-rich water (as would be encountered in or near sewage outfalls) (Abidi 1982), the occurrence of environmental stress in natural aquatic systems has not been reported.

14. It is assumed that dye, once injected into a body of water, behaves in a manner similar to that of individual molecules of water and thus allows characterization of water movement. Critical to this assumption is the requirement that the dye be sufficiently dilute so as to approximate ambient water density. Rhodamine WT is obtained commercially as a 20-percent aqueous solution (specific gravity = 1.2) and requires preinjection dilution in situations in which turbulent, postinjection mixing is minimal. Such was the case during all but the initial injections into the well-mixed, rapidly flowing reach of the river immediately above West Point Lake. As will be noted below, on one occasion insufficient dilution apparently resulted in sinking of the dye.

15. Initial dye injections were made from atop the bridge at Franklin, Ga., on 26 October 1980 (first study) and 22 July 1981 (second study) by allowing diluted dye to gravity flow from a 380-ℓ fiberglass tank mounted on a flat-bed truck through a 20-m section of 2.5-cm polyethylene tubing, the discharge end of which was submerged and fitted with a polyvinyl chloride (PVC) "T" to prevent initial sinking of the dye. The Chattahoochee River at this location is fast flowing and shallow; therefore, the dye was well mixed immediately downstream from the point of discharge. Dye solution of 15 and 37.9 ℓ, diluted with river water to a total volume of approximately 375 ℓ, was injected on 26 October 1980 and 22 July 1981, respectively. Ideally, the initial

injections were to have created a "slug" of dye; however, time required to discharge the dye (5 to 6 min) and the rapid flow of the river resulted in the formation of a dye "streak" approximately 100 to 150 m long and 15 to 20 m wide on each occasion. This initial spreading of the dye was not considered to be a significant deviation from the requirements of the experiment.

16. Dye concentrations were determined fluorometrically by pumping lake water from various depths to the flowthrough cell of a Turner Designs Model 10 Fluorometer (Turner Designs, Mountain View, Calif.) on board one of two boats employed during both studies. This apparatus allowed quantification of dye distribution at concentrations as low as 0.01 mg/ℓ.

17. Location of the dye was estimated each day based on its position the previous day and flow recorded upstream at Whitesburg, Ga. This procedure assumed vertical and lateral mixing of river water in the lake and provided estimates of travel distance based on time since last sampling and longitudinal changes in volume. Calculations made during the October 1980 study, when the lake was not thermally stratified, were relatively accurate, while those in July 1981 provided erroneous estimates due to violations of the vertical and lateral mixing assumptions. As will be discussed, flows during this study were influenced by vertical stratification of the lake.

18. More detailed estimates of the location of the center of the dye mass, and thus the approximate location of the center of the original parcel of water considered during each of the studies, were based on fluorometrically determined dye concentrations at several depths and locations. Samples taken at widely separated stations in the vicinity of the calculated location of the center of the dye mass allowed initial evaluation of dye distribution. These estimates were refined by more intensive sampling. Delineation of the dye mass and location of its center required approximately 1 hr.

19. Decreases in dye concentration by dispersion and/or mixing necessitated daily reinjections of dye to ensure that detectable concentrations were maintained throughout each study. This was accomplished

using a procedure similar to that employed for the initial land-based injections. Dye, the quantity of which was estimated daily from observed decreases during the previous period, was diluted with lake water pumped from the anticipated injection depth. Injections were accomplished by gravity flow using the above-mentioned tubing weighted at the end and fitted with a T-shaped plumbing fixture to ensure lateral dispensing of the dye. Unlike during injections from atop the bridge, the center line of the dye-containing tank during lake injections was only 1.5 m above the water surface; thus, 15 to 20 min was required for injections. The degree to which dye was mixed with lake water following injection could not be measured, but was assumed to be sufficient to prevent sinking due to high dye concentrations. Quantities of dye used, dates and times of injections, and injection locations are presented in Table 2 and Figure 3.

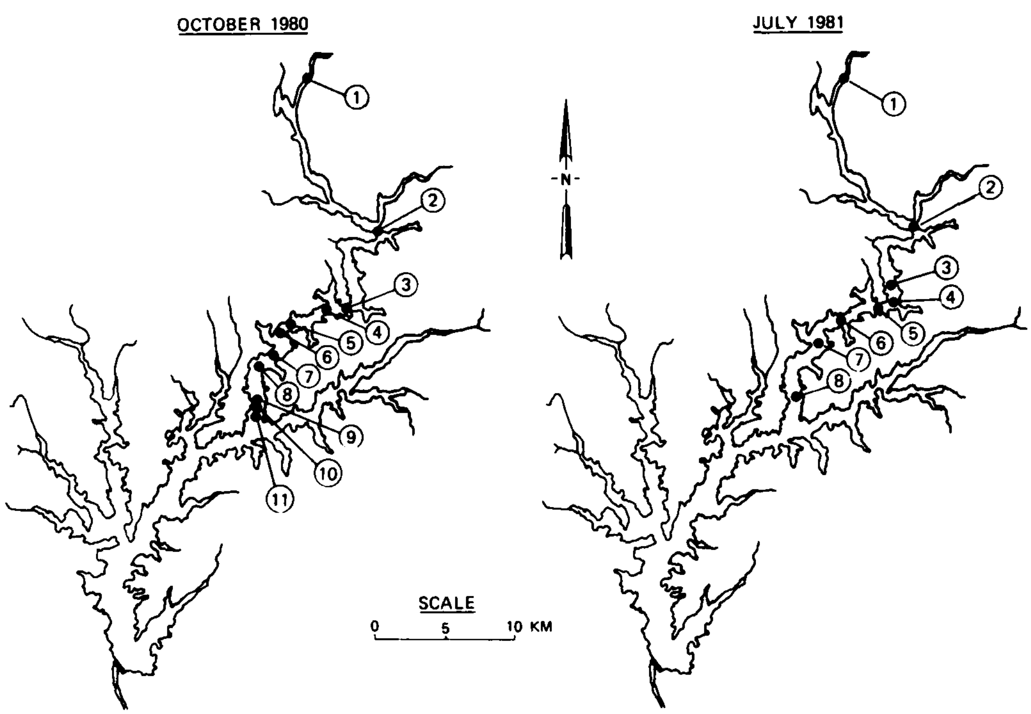

Figure 3. Location of sampling and dye injection stations in West Point Lake (circled numbers represent stations)

Sampling Procedures

20. Samples for initial characterization of the river were collected at Franklin immediately prior to dye injection. Subsequent samples were collected from the center of the dye mass prior to injection of additional dye. The depth and location at which a sample was collected was determined by dye distribution. During the October 1980 study, samples were collected twice daily: once in the morning and again in late afternoon or early evening. Daily samples were obtained during the July 1981 study. Sample times and locations are presented in Table 2 and Figure 3, respectively.

21. Replicate samples were obtained from the center of the dye mass using tubing and a centrifugal pump, and stored in separate opaque polyethylene carboys prior to sample analysis or preservation. Once initiated, collection of replicate samples was completed as soon as possible to eliminate differences related to flow or drifting of the sampling boat. In situ measurements at the sampling depth and at 1-m intervals from surface to bottom were obtained using a Hydrolab Model 8000 (Hydrolab Corp., Austin, Tex.). Variables measured included dissolved oxygen, pH, temperature, and specific conductance.

22. In situ profile measurements were also obtained at two additional stations located to either side of the primary sampling station along a transect perpendicular to the thalweg. The exact locations of these stations were determined by local morphometry, but in general were at locations having water column depths approximately one half that of the primary station. These data were intended to provide information concerning possible cross-sectional differences.

23. In situ profiles were also obtained daily at selected stations between the extreme upstream end of the lake and Yellowjacket Creek, the anticipated downstream extent of the study area. Measurements were taken at 1-m intervals from surface to bottom over the locally deepest point of the channel. Longitudinal station locations are indicated in Figure 4. These data, which were acquired over a period of approximately 2 hr in midafternoon, provide general information

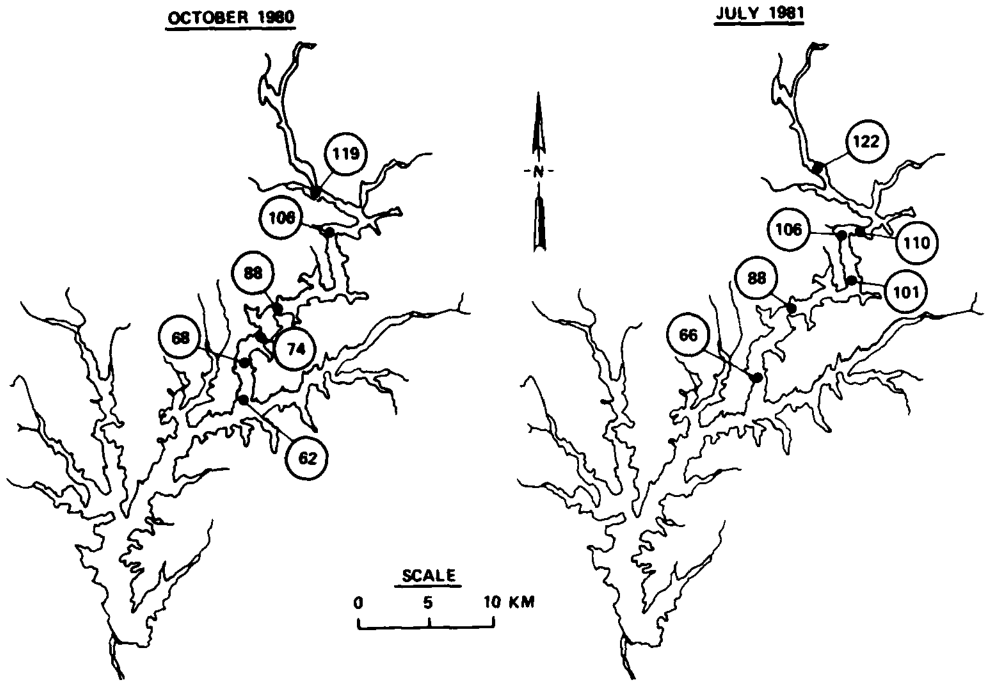

Figure 4. Location of longitudinal, in situ sampling stations in West Point Lake

concerning conditions throughout the study area on each of the study days.

Analytical Procedures

24. Each replicate sample was mixed prior to removing subsamples by gently inverting the carboy sample containers. Care was taken to avoid agitation while still ensuring that suspended materials were evenly mixed. Subsamples were vacuum filtered (≤ 1 atm.) using either 0.45-μ membrane filters or glass-fiber filters, depending on analytical requirements, or preserved and stored unfiltered. Filters, when required for later analysis, were placed in covered, plastic containers and stored in the dark at 4° C. Filters for pigment analyses were later frozen. All filtrations were completed within 1 hr of sample collection. Turbidity and total alkalinity analyses were performed onsite, while all other analyses were conducted in contract laboratories or at WES.

Samples were transported to the laboratories as soon after collection as possible (generally daily) by vehicle or overnight air express.

25. Sample preparation and preservation techniques and analytical methods are outlined in Table 3. Unless otherwise specified, particulate concentrations were calculated as the difference between dissolved and total concentrations.

PART IV: RESULTS

Thermal Structure

26. The thermal structure of West Point Lake was different during each of the studies. The lake was weakly stratified during the July 1981 study but nearly isothermal for the October 1980 study. These seasonal differences are apparent from data collected daily at selected stations throughout the study reach. During the period 26-31 October 1980, longitudinal and vertical differences in temperature, dissolved oxygen, and specific conductance were minimal (Figures 5-7, respectively). Vertical and longitudinal differences were apparent, however, during the period 23-29 July 1981 (Figures 8-10). Vertical temperature differences in the deeper, downlake portion of the study area indicated a broad, weak thermocline below a depth of approximately 7 m; however, a true hypolimnion (i.e. a zone of deep, cool, relatively isothermal water) did not exist. The upstream half of the study area was intermittently stratified and apparently strongly influenced by riverflow. Downward displacement of isotherms at or near station 106 and recorded observations of surface conditions (e.g. bubble formation, debris accumulation, etc.) indicated this as the approximate location of the plunge point.

27. Coincident with the thermocline in July 1981 were pronounced changes in dissolved oxygen concentrations and specific conductance. Conductivity in surface waters and throughout the entire water column above station 106 ranged from 75 to 90 μmhos/cm. Similar values were recorded for river water at Franklin, Ga., on 22 and 23 July. Conductivities were highest (90 to 160 μmhos/cm) in deep, downlake areas of the study reach. Dissolved oxygen concentrations increased with distance downlake in the epilimnion, but decreased with depth. Bottom waters at stations 88 and 66 were anoxic throughout the July 1981 study.

Inflow Characteristics

28. Riverflows were similar during both study periods (Figure 11). Daily mean flows during the October 1980 study ranged from

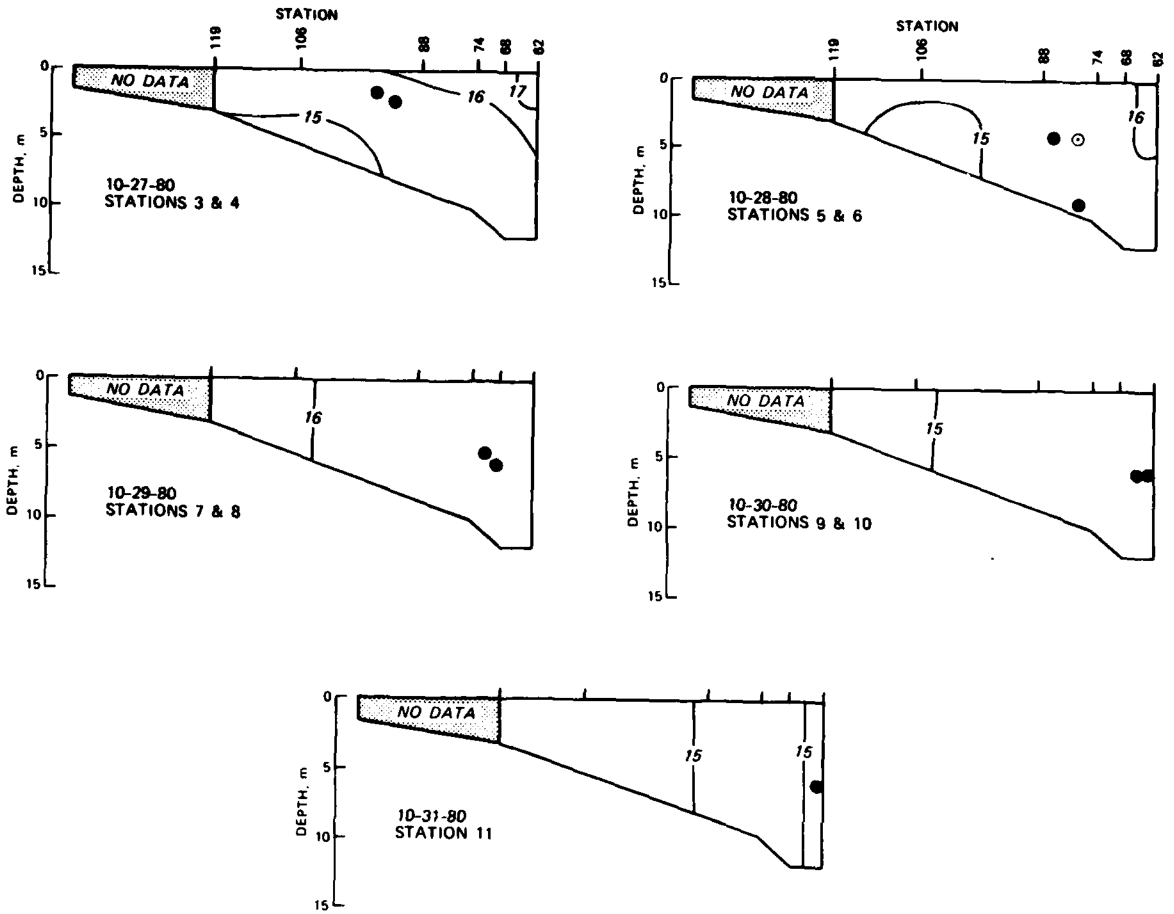

Figure 5. Vertical and longitudinal distribution of temperature (°C) in the upstream portion of West Point Lake during the October 1980 study. Depth and location of the center of the dye mass are indicated by closed circles. Open circle indicates adjusted depth for dye injection (see paragraph 30 for explanation)

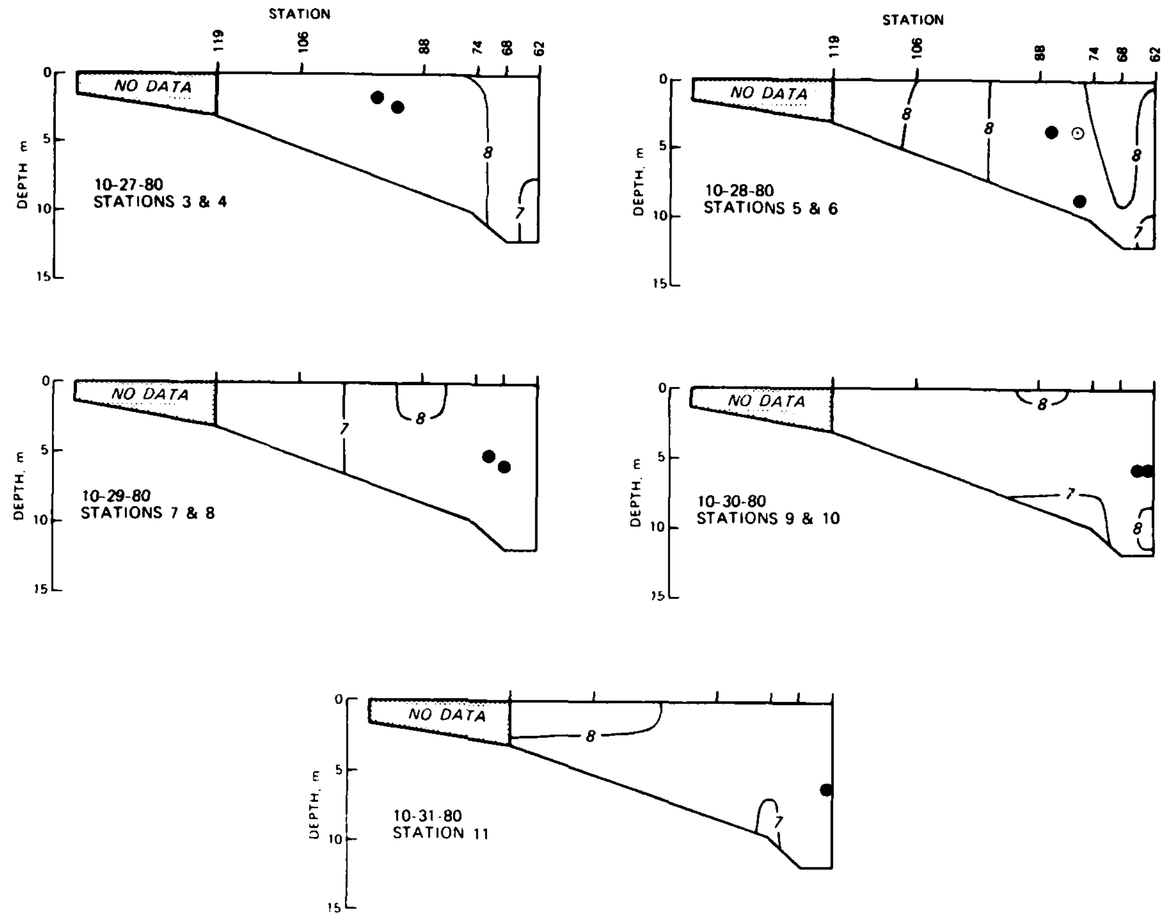

Figure 6. Vertical and longitudinal distribution of dissolved oxygen ($mg\ O_2/\ell$) in the upstream portion of West Point Lake during the October 1980 study. Depth and location of the center of the dye mass are indicated by closed circles. Open circle indicates adjusted depth for dye injection (see paragraph 30 for explanation)

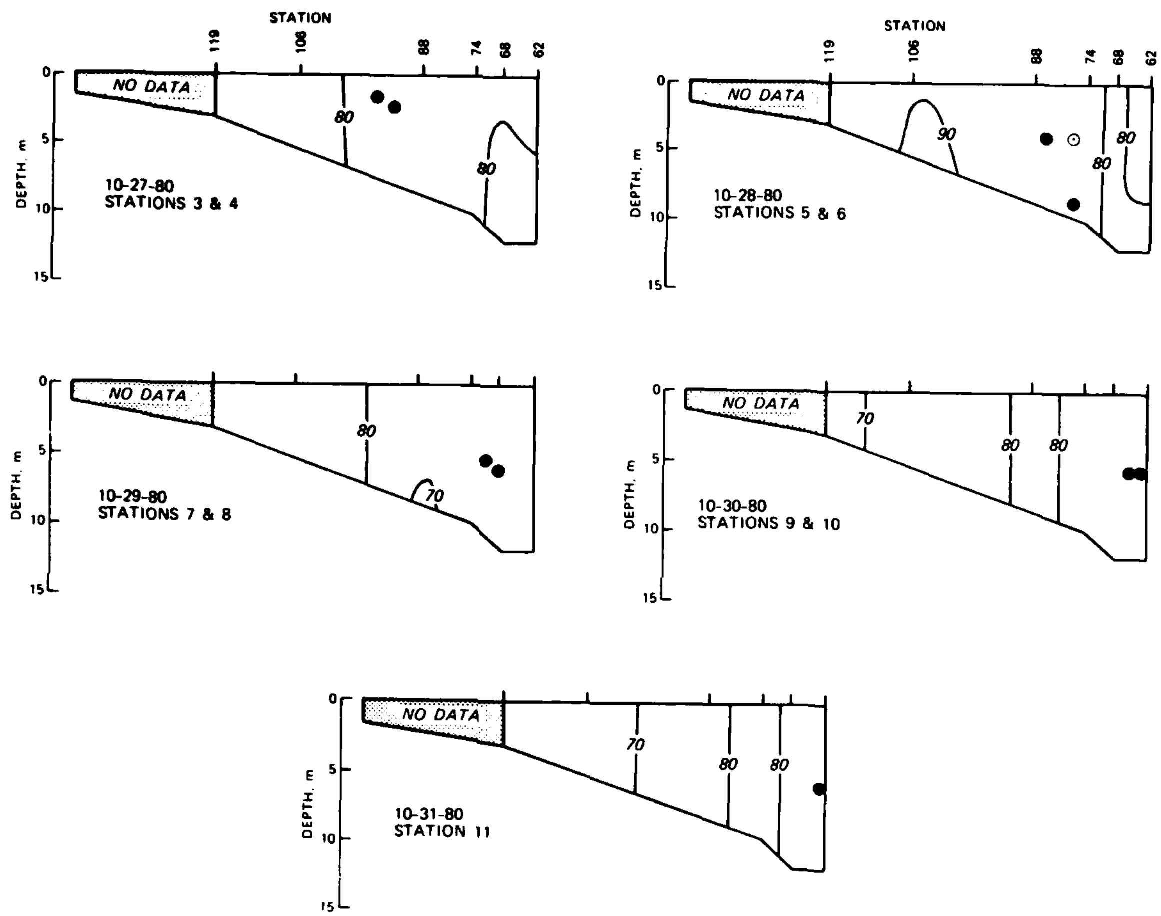

Figure 7. Vertical and longitudinal distribution of specific conductance (µmhos/cm at 25° C) in the upstream portion of West Point Lake during the October 1980 study. Depth and location of the center of the dye mass are indicated by closed circles. Open circle indicates adjusted depth for dye injection (see paragraph 30 for explanation)

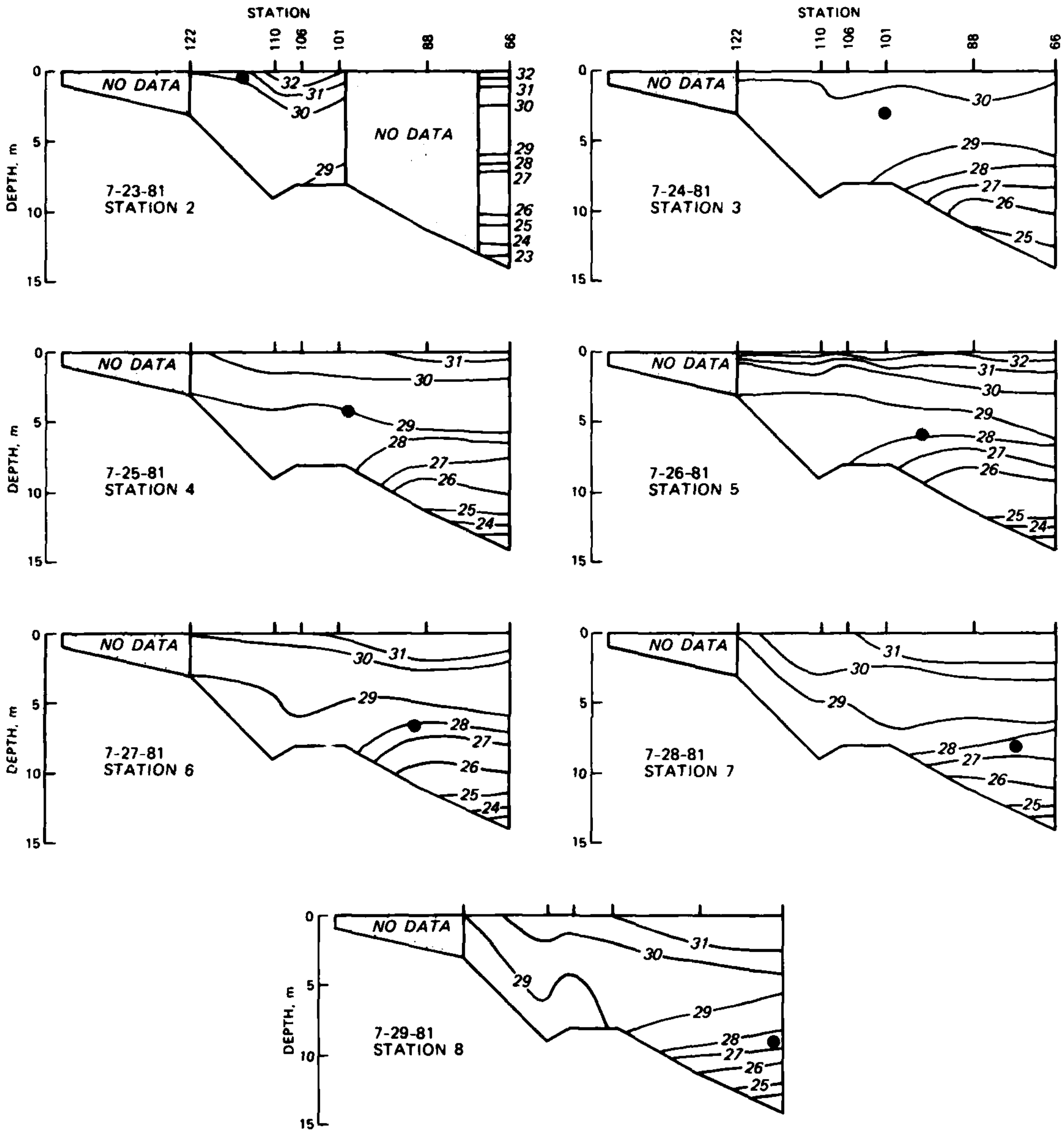

Figure 8. Vertical and longitudinal distribution of temperature (°C) in the upstream portion of West Point Lake during the July 1981 study. Depth and location of the center of the dye mass are indicated by closed circles

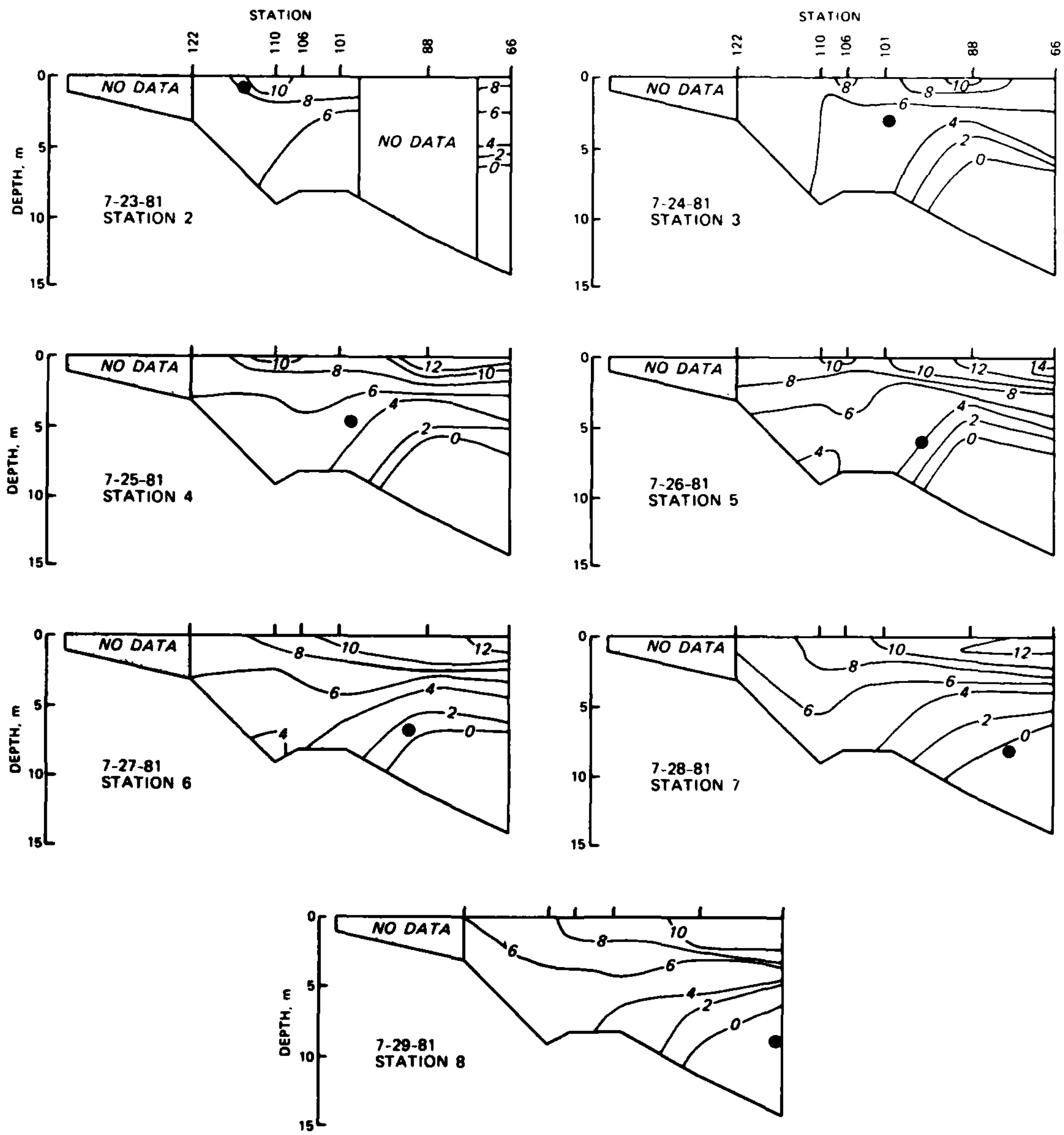

Figure 9. Vertical and longitudinal distribution of dissolved oxygen ($mg\ O_2/\ell$) in the upstream portion of West Point Lake during the July 1981 study. Depth and location of the center of the dye mass are indicated by closed circles

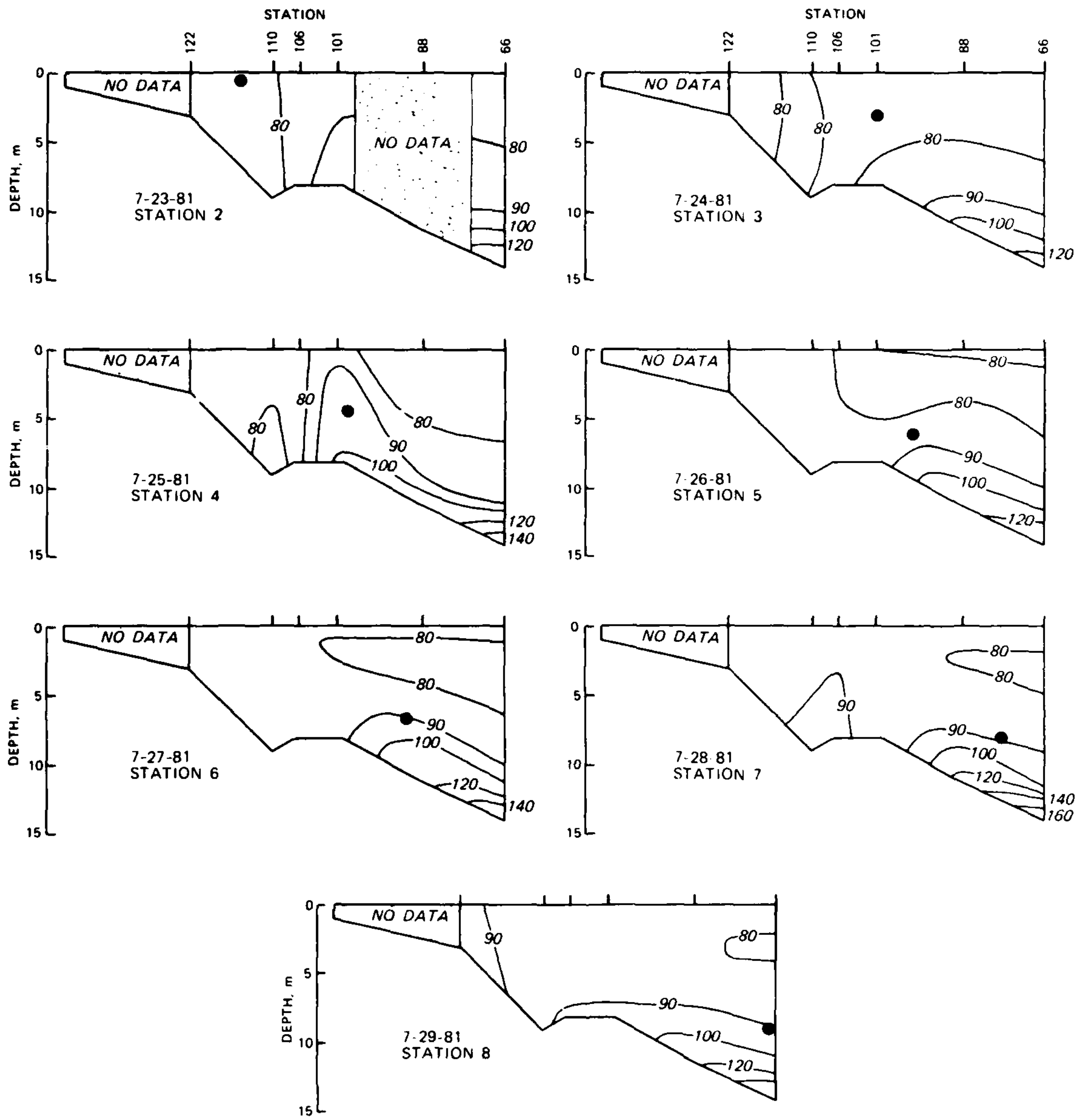

Figure 10. Vertical and longitudinal distribution of specific conductance (μmhos/cm at 25° C) in the upstream portion of West Point Lake during the July 1981 study. Depth and location of the center of the dye mass are indicated by closed circles

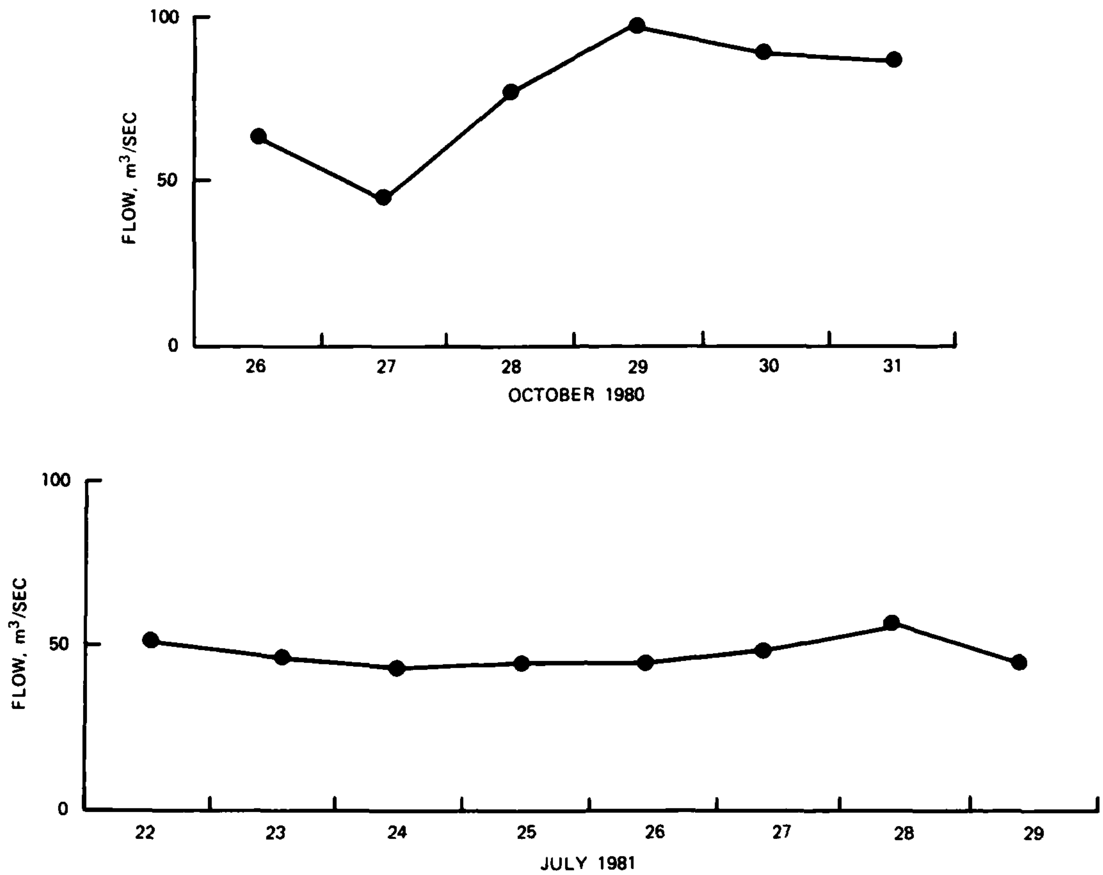

Figure 11. Changes in daily mean flow in the Chattahoochee River during the study (based on data for Whitesburg, Ga., as reported by U. S. Geological Survey (USGS) 1980, 1981)

45 to 104 m^3/sec; those during the July 1981 study ranged from 43 to 58 m^3/sec. These flows are typical of the late-summer and fall seasons during which flows are characteristically low and relatively constant (Figure 12).

29. Inflow regimes during each study reflect seasonal differences in the thermal structure of the lake. Inflows were vertically well mixed during the October study, but plunged and were conveyed as an interflow during the July study. These conclusions are supported by dye distributions as well as in situ data collected daily along the study reach.

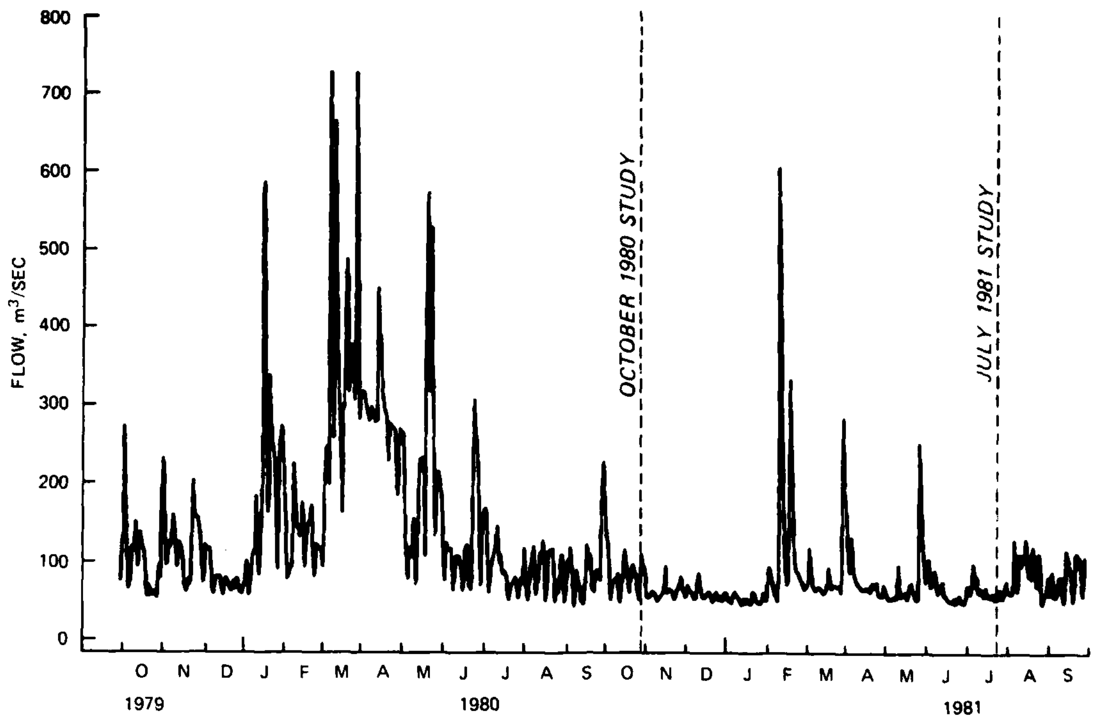

Figure 12. Changes in daily mean flow in the Chattahoochee River during the period October 1979 to September 1981 (based on data for Whitesburg, Ga., as reported by USGS 1980, 1981)

30. Vertical profiles of relative dye concentration, expressed as a percent of the maximum observed concentration at each sampling location, indicate a nearly uniform distribution at all but three sampling times during the October study (Figure 13). Nonuniform distributions may have resulted from improper dye injections during the previous day's sampling. Excessive amounts of dye and/or poor mixing at the point of dye discharge would result in higher local densities and thus sinking of the dye mass. This problem apparently occurred at station 5 since the dye mass at station 6 was located well below the expected depth. Reinjection of dye at this station was therefore conducted at a depth indicated by the position of the dye at the previous station.

31. There were no visual observations to suggest that inflows were other than well mixed during the October study. Lines of debris or discontinuities in surface turbidity, characteristics commonly associated with plunging density flows, were lacking. Streaks of dye

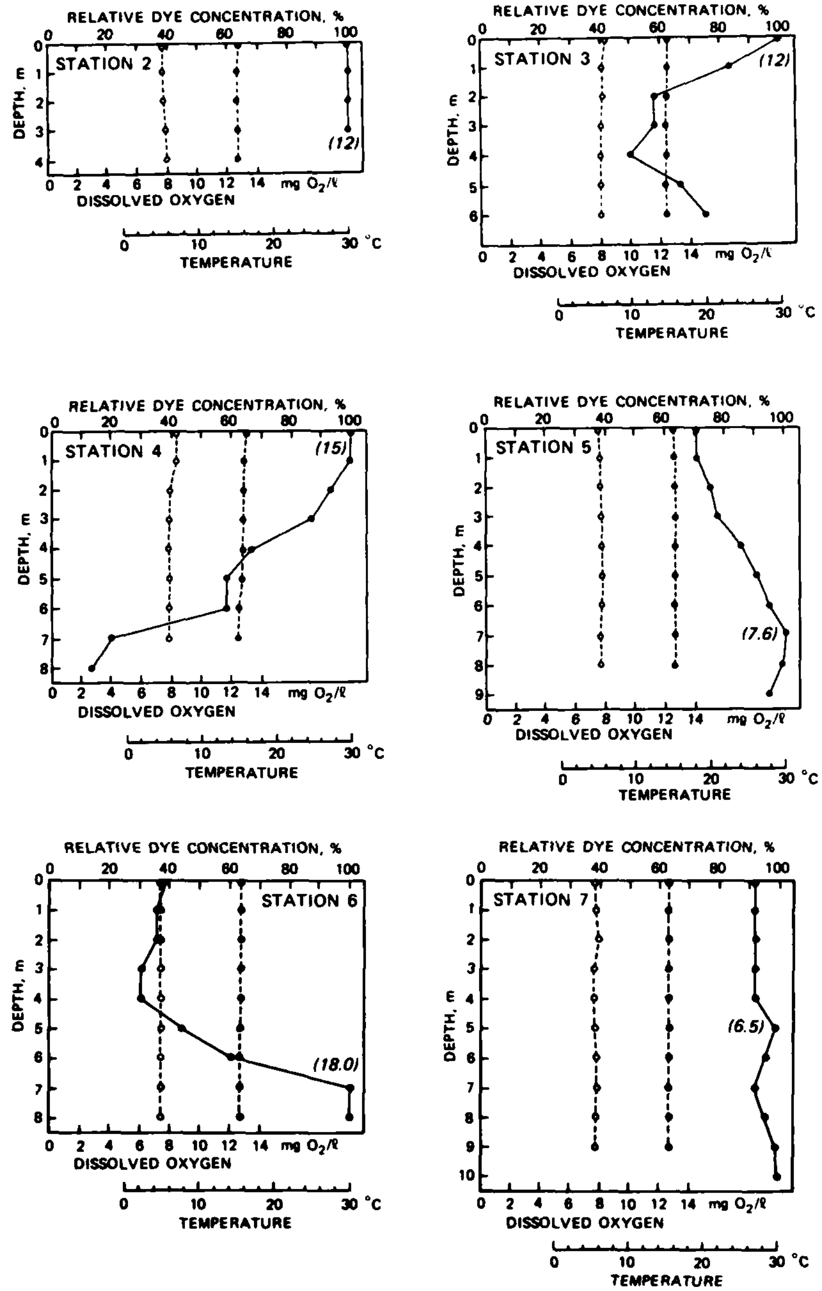

Figure 13. Depth distribution of relative dye concentration (●—●), temperature (●--●), and dissolved oxygen (o---o) during the October 1980 study. Maximum dye concentration (μg/ℓ) is indicated in parentheses at depth of observation (Continued)

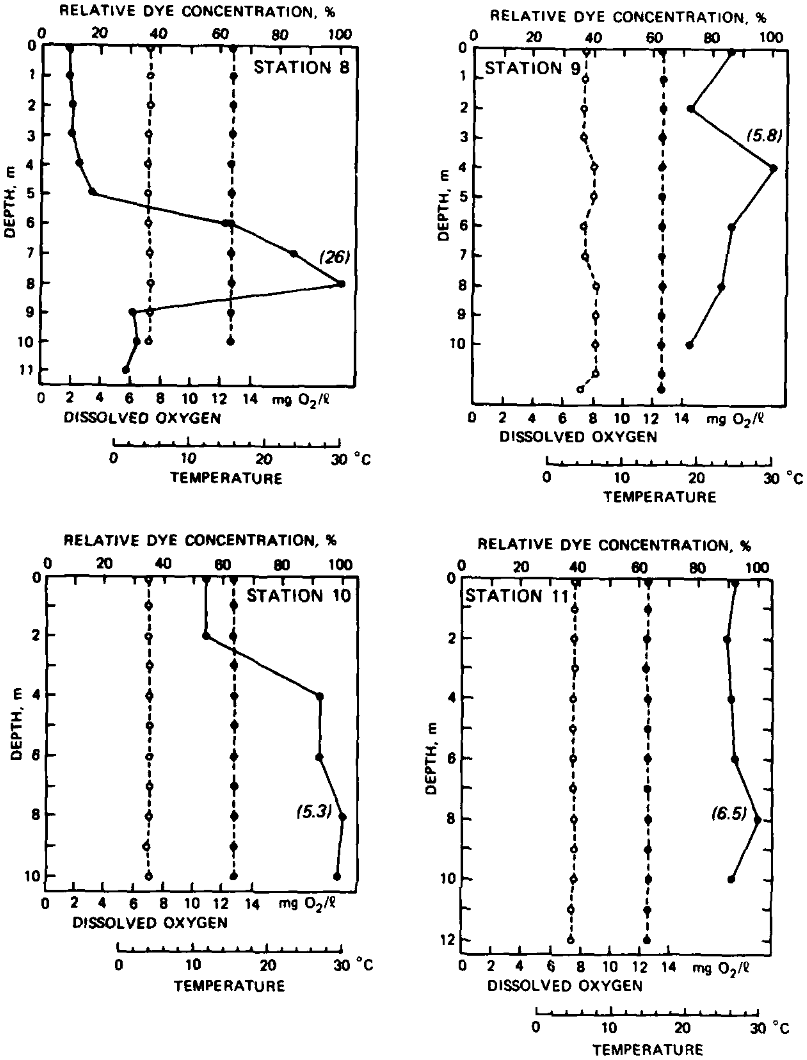

Figure 13. (Concluded)

1.5 to 4.0 km long (decreasing in length with distance downlake) were detectable at the surface during the entire study. Since injections of dye were made at depths ranging from 1 to 6 m, this would indicate at least partial vertical mixing.

32. Profiles of relative dye concentration observed during the July 1981 study (Figure 14) document the occurrence of an interflow immediately above the thermocline. Dye concentrations were highest near the surface at station 2, the first in-lake sampling station, but relatively uniform at station 3. Concentration at station 4 was highest at

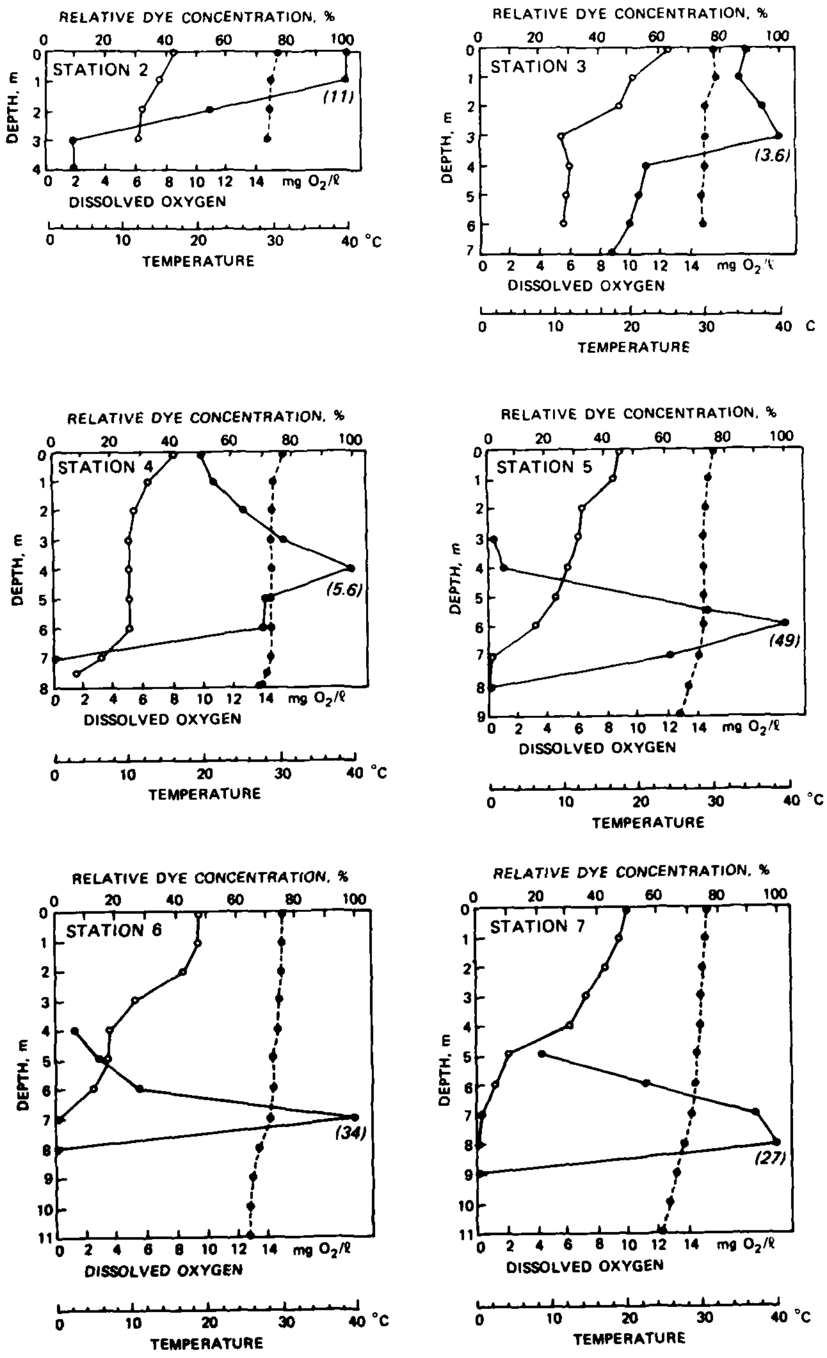

Figure 14. Depth distribution of relative dye concentration (●—●), temperature (●--●), and dissolved oxygen (o——o) during the July 1981 study. Maximum dye concentration (μg/ℓ) *is indicated in parentheses* at depth of observation (Continued)

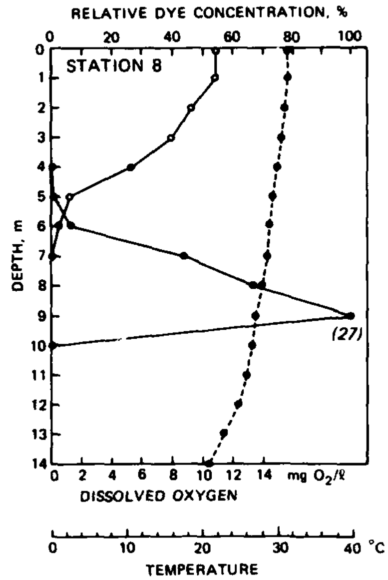

Figure 14. (Concluded)

4 m. Concentrations declined sharply below 4 m but were relatively high in surface waters, possibly indicating the occurrence of mixing above the riverine layer. Station 4 was located immediately downstream from the apparent location of the plunge point, based on observations of surface conditions and longitudinal in situ data (see Figures 8-10). Flow velocity was noticeably reduced in this area and debris accumulated across the width of the channel. Surface turbidity, however, was not visibly changed.

33. Inflowing water was confined to strata of intermediate depth downstream from station 4. Depths of maximum dye concentration ranged from 6 m at station 5 to 9 m at station 8. Dye concentrations below the depth of maximum concentration declined sharply, while changes above this depth were more gradual. Depths of maximum dye concentration at stations downstream from the plunge point coincided with the approximate location of the top of the thermocline. Between stations 2 and 5, the center of the dye mass sank to a depth below which specific conductivity was markedly higher than that for surface waters (see Figure 10). The path traveled by the dye between stations 6 and 8 indicates that the riverine layer did not penetrate to bottom waters having conductivities

exceeding 90 μmhos/cm. This observation, and in situ data for temperature and dissolved oxygen concentration (see Figures 8 and 9), further suggest the occurrence of an interflow of riverine water immediately above the thermocline.

34. Patterns of change in flow velocity, calculations of which were based on the travel time of dye between successive sampling locations, were different during the two studies (Figure 15). During the October 1980 study, flow velocity in the vicinity of the river inflow averaged 16.7 cm/sec. Velocity declined between stations 2 and 3, and again between stations 8 and 9. Flow velocities between station 3 and 8, and between station 9 and 11 averaged 4.7 and 0.8 cm/sec, respectively. This pattern of change in flow velocity during the October 1980 study, which occurred when riverflow was relatively stable, is similar to the pattern of longitudinal change in lake volume. This further supports the contention that inflowing river water was vertically and

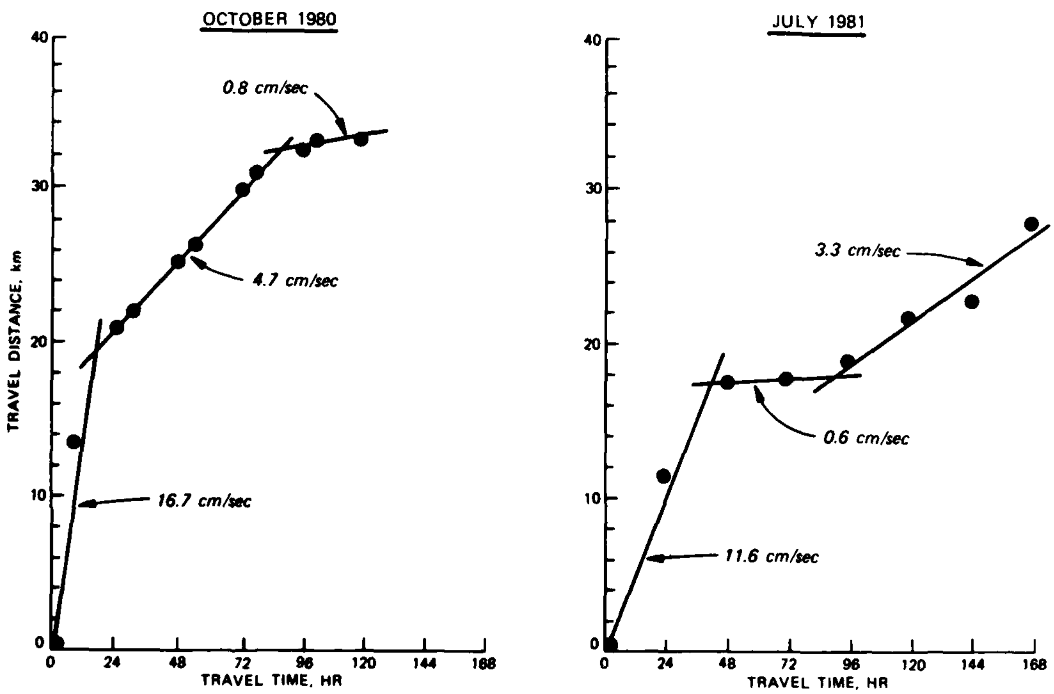

Figure 15. Travel distance of the dye mass as a function of travel time during the October 1980 and July 1981 studies. Lines indicate approximate flow velocities as computed from travel distance and time

laterally well mixed during this period.

35. The pattern of change in flow velocity during the July 1981 study was influenced by the occurrence of the density interflow. Flow velocity averaged 11.6 cm/sec initially but decreased to 0.6 cm/sec along the 1-km reach from station 2 to 5. This corresponds to the general location of the plunge point. Flow velocity beyond the plunge point averaged 3.3 cm/sec. Decreased velocities near the plunge point and increases downlake from the plunge point reflect complex interactions between river momentum and buoyancy forces in the lake (Ford and Johnson 1983). As inertial forces diminish with increases in basin width and depth, riverine water, which is prevented from completely mixing with the lake's surface waters by density differences, is confined to strata of similar density. This occurrence causes riverine water to "stall" or "pool" in the vicinity of the plunge point. Velocity below the plunge point increases as inflowing water is confined to a relatively narrow stratum immediately above the thermocline.

Water Quality

36. Physicochemical conditions in the river immediately above West Point Lake were relatively similar on the first day of each study (Table 4). Exceptions included temperature, median particle size of suspended material, and concentrations of total organic carbon, inorganic nitrogen, and particulate iron. A comparison with average river water quality characteristics for the period October 1979 through September 1981 (Table 4) indicates that, in general, each of the studies was conducted during periods when water quality conditions in the river were other than extreme. This may also be inferred from the fact that flows prior to each study were seasonally normal and relatively stable. Since flow was distributed relatively uniformly across the river, samples collected at mid-stream were considered representative. In general, the river at Franklin, Ga., was well oxygenated, turbid, and had high nutrient and organic matter concentrations.

37. Data collected at downstream locations on subsequent days,

which document changes in water quality associated with processes occurring in the upstream areas of West Point Lake, are presented in the paragraphs to follow. The location of the parcel of water considered during each of the two studies can be referenced by station number, distance from the river, or time since the initial sample was collected (Figure 16). Since it was assumed that the impounding of river water would result in time-dependent changes in water quality, the latter means of data presentation has been adopted for much of the discussion which follows. This method of presentation also facilitates comparisons between the results of these studies.

Temperature

38. Changes in the temperature of the inflowing parcel of water were slight during both studies (Figure 17). Temperatures during the October 1980 study ranged from 14.9 to 15.6°C and displayed no trend. During the July 1981 study, however, time-related differences were apparent. The temperature of the inflowing parcel of water downstream from the plunge point averaged 28.5°C; temperatures upstream from the plunge point averaged 31.4°C. The difference, 2.9°C, may have resulted from the fact that inflowing river water was confined as an interflow. This would reduce radiant and conductive heat gain. The decrease in temperature may also indicate the entrainment of cooler, bottom waters in the vicinity of the plunge point.

Dissolved oxygen

39. Dissolved oxygen concentrations, which were relatively unchanged during the October 1980 study, declined markedly with time during the July 1981 study (Figure 17). Concentrations prior to the arrival of the water parcel at the plunge point were near saturation. However, concentrations downstream from the plunge point decreased steadily at a rate of 1.56 mg/ℓ/day ($r^2 = 0.98$) and anoxic conditons (<0.5 mg/ℓ) were reached over a period of approximately 83 hr. As with temperature, the isolation of river water at intermediate depths downstream from the plunge point would limit exchanges at the air-water interface. The prevention of reaeration and the presence of a large pool of oxidizable material would lead to the observed oxygen depletion.

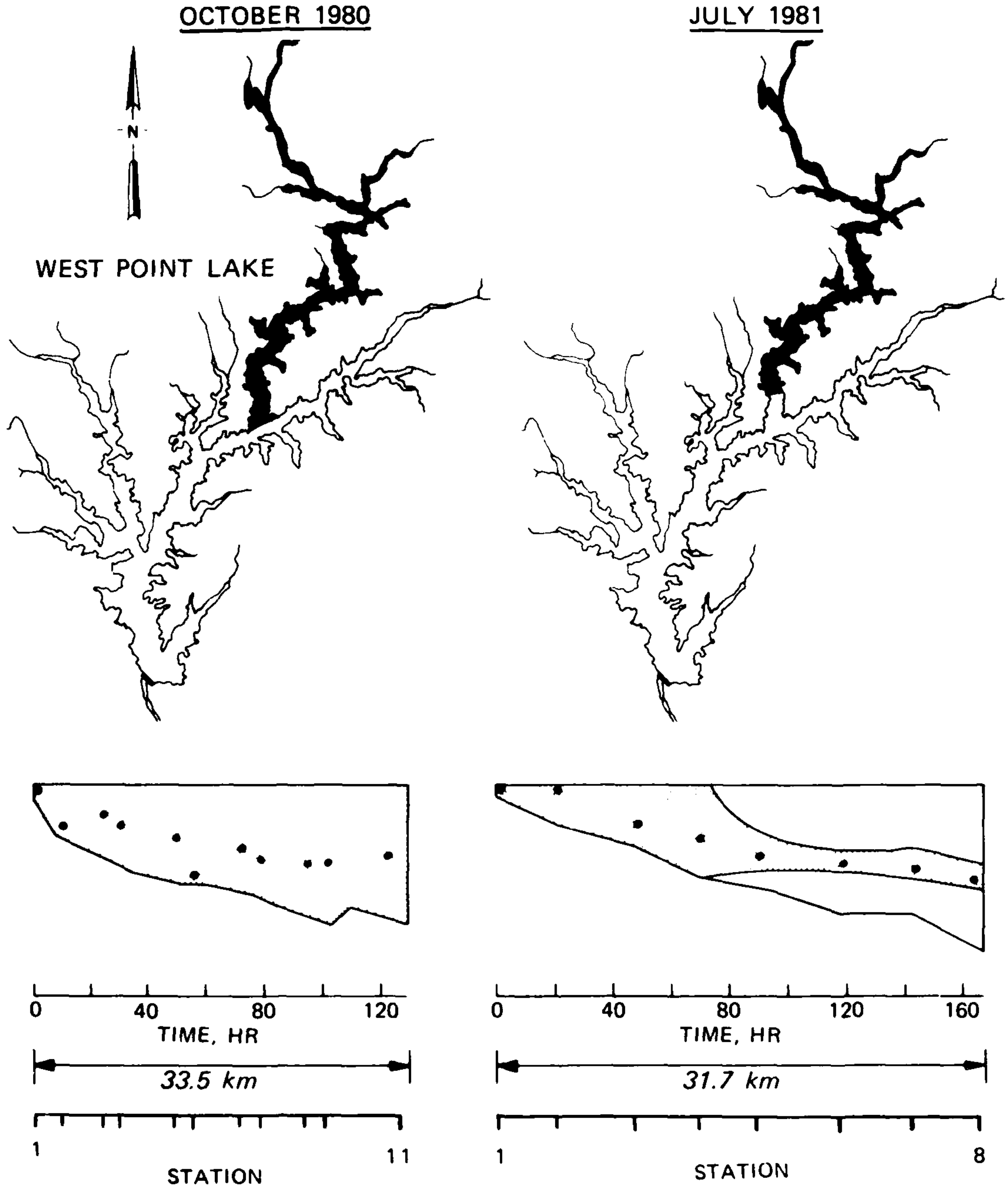

Figure 16. Maps indicate the extent (shading) of the study area during the October 1980 and July 1981 studies. Longitudinal section diagrams indicate sampling depths (closed circles) and depths at which relative dye concentration exceeded 25 percent (stippling) as a function of time and station number

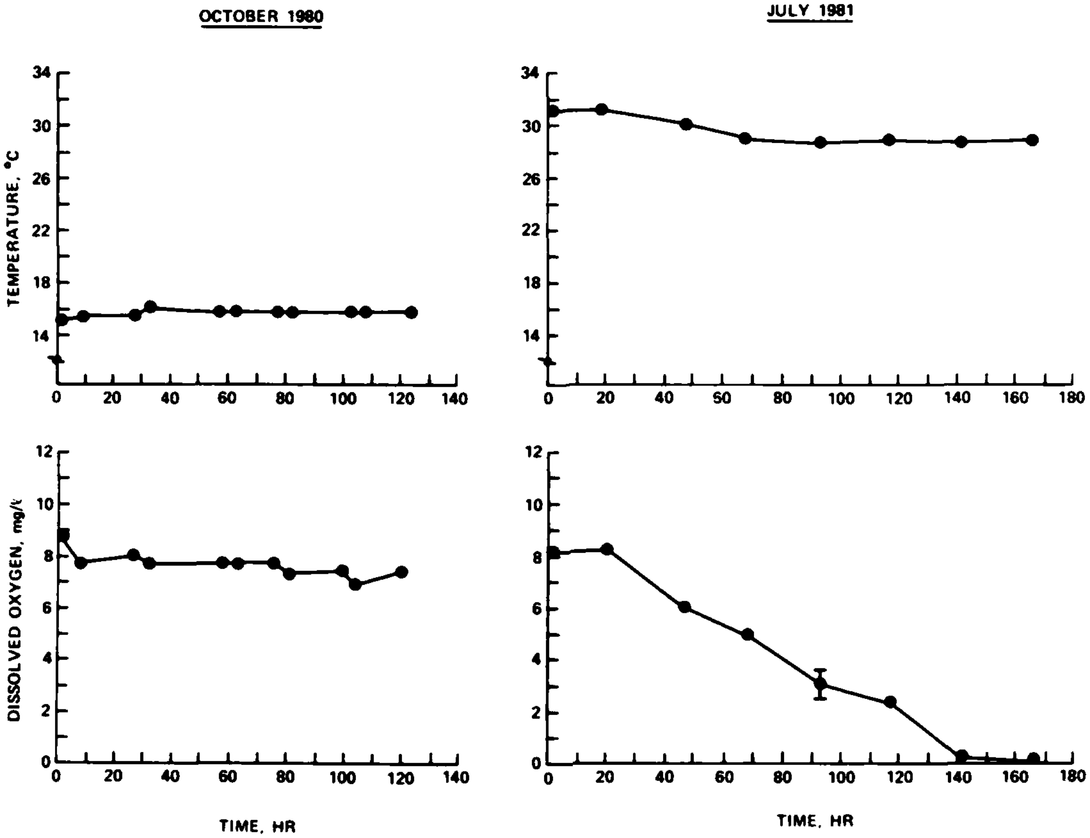

Figure 17. Changes in temperature (upper) and dissolved oxygen (lower)

Specific conductance

40. Dissimilar patterns of change in specific conductance were observed during the two studies (Figure 18). In October 1980, conductivity remained relatively constant during the first half of the study, but decreased abruptly after approximately 60 hr and then remained constant. Although the decline in conductivity occurred near the location of the apparent improper diluting of dye (i.e. station 5), longitudinal profiles of the lake taken the same day indicate an overall decline in conductivity (see Figure 7).

41. Specific conductance during the July 1981 study, although variable during the first 48 hr, increased slightly in the lower reaches of the study area. Increases here may have been related to mixing and

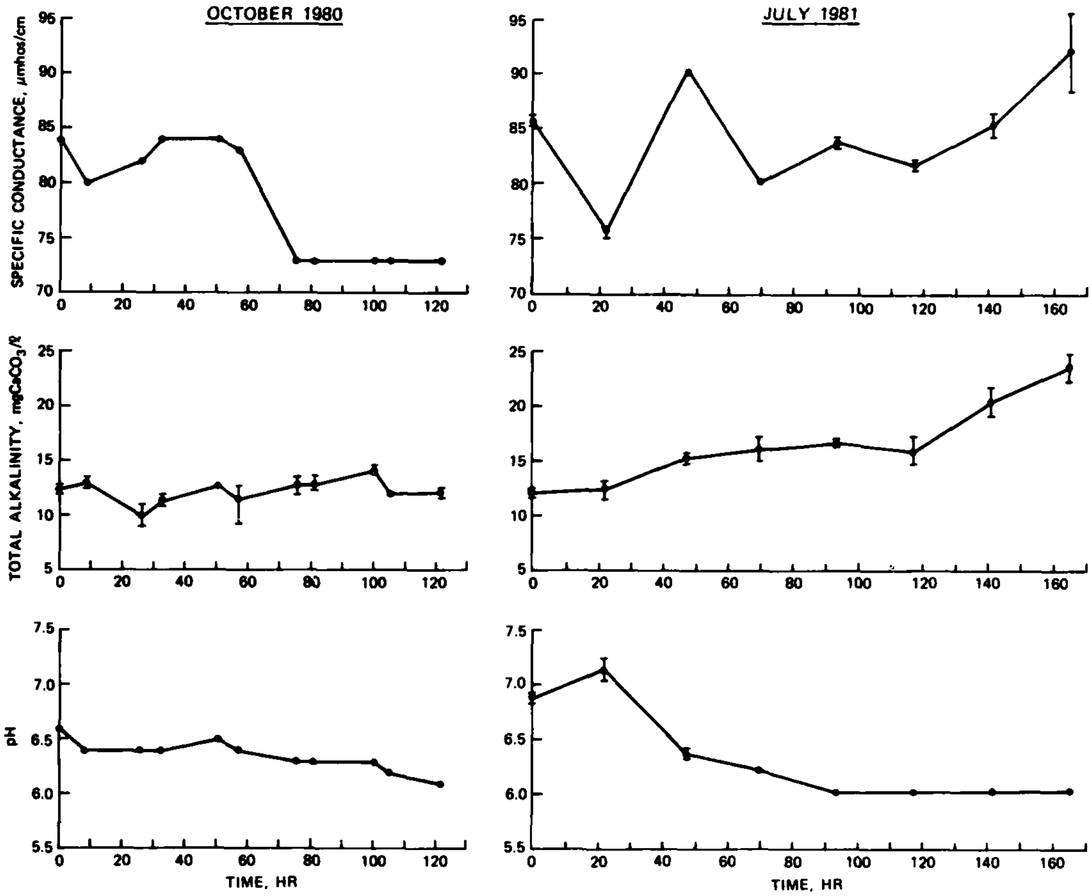

Figure 18. Changes in specific conductance (upper), total alkalinity (middle), and pH (lower)

entrainment since waters in strata immediately below the interflow had higher conductivity (see Figure 10).

pH and total alkalinity

42. Between-study comparisons indicate similar trends of change in pH and total alkalinity with time (Figure 18). With the exception of samples taken prior to the arrival of the water parcel at the plunge point during the July 1981 study, pH decreased and total alkalinity increased with time. Higher values of pH during the July 1981 study were possibly due to an initial higher pH in the river and/or elevated rates of algal productivity, as inferred from chlorophyll a concentrations in upstream areas of the lake.

Turbidity, suspended
solids, and particle size

43. During both study periods, changes in turbidity reflected changes in suspended solids (Figure 19). In general, both decreased through time. A noticeable and unexplained exception occurred at the most downstream station during the July 1981 study. Turbidity and

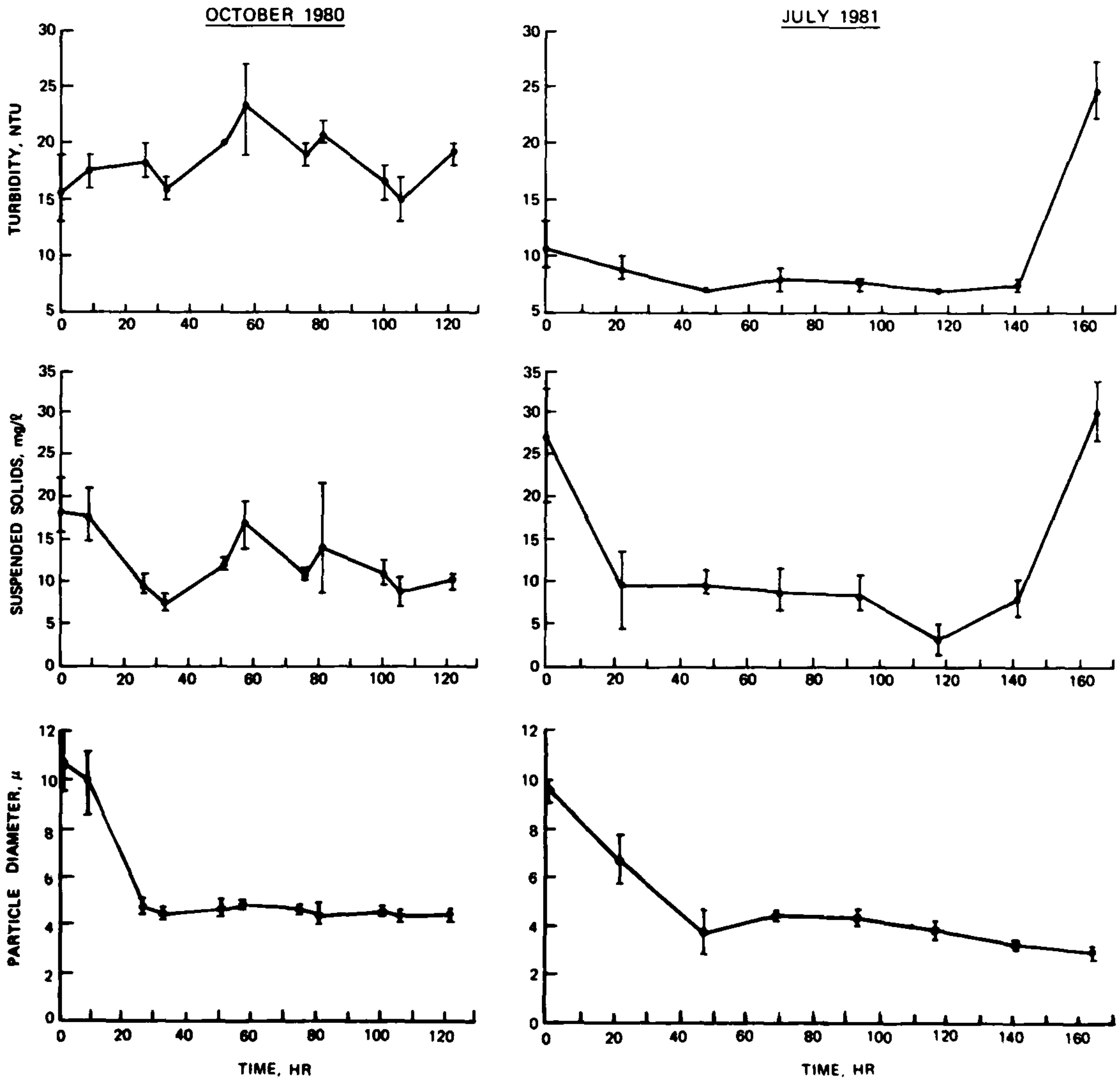

Figure 19. Changes in turbidity (upper), suspended solids (middle), and median particle size (lower)

suspended solids concentration at this station increased approximately threefold.

44. Changes in suspended solid particle size during the October 1980 and July 1981 study indicate the loss of larger particles by sedimentation or by particle degradation in the upper reaches of the study area. Median particle size decreased by approximately 50 percent during the first 24 to 48 hr of each study and then remained relatively unchanged (Figure 19).

Algal pigment

45. Changes in chlorophyll a concentration during each study period were dissimilar (Figure 20). During the October 1980 study, concentrations, although initially variable, displayed an increasing trend. In July 1981, chlorophyll concentration increased threefold as river water progressed through the most upstream portion of the study area. Concentrations declined markedly, however, as the inflow water

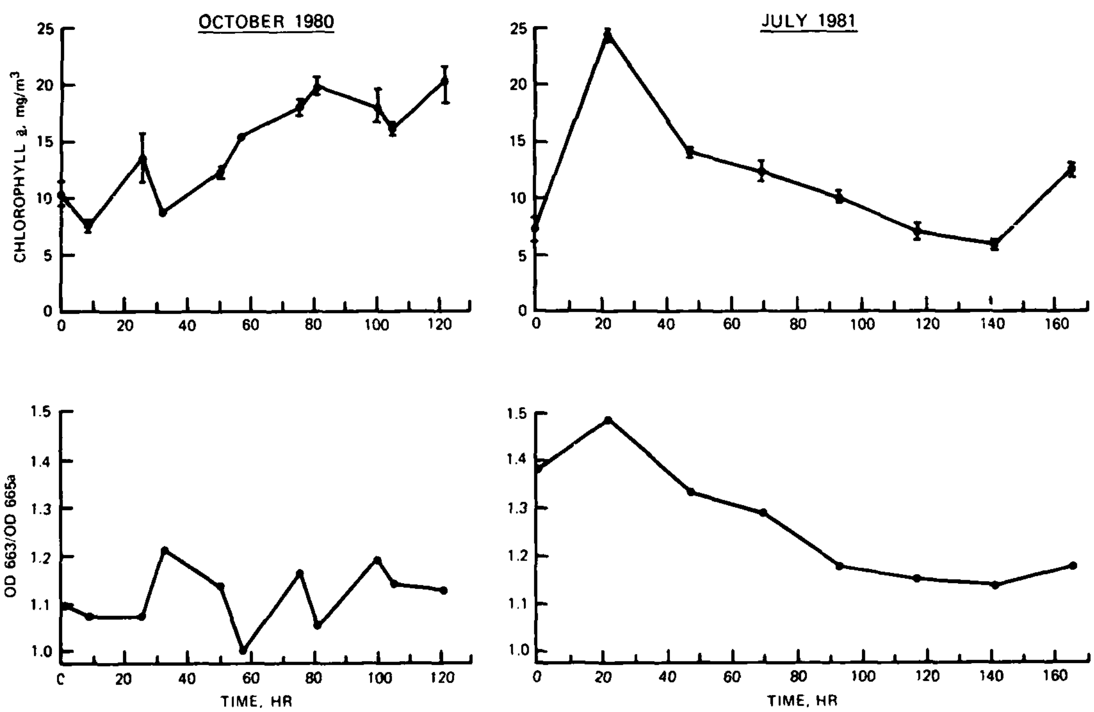

Figure 20. Changes in chlorophyll a (upper) and optical density (lower)

progressed past the plunge point. Concentrations continued to decline, although at a lower rate, during the remainder of the July study.

46. Changes in the ratio of optical density (OD) at 663 nm before acidification to OD at 665 nm after acidification (OD 663/OD 665a), which provides an index to the physiological state of algae (American Public Health Administration (APHA) 1980), were also dissimilar (Figure 20). Despite the fact that chlorophyll concentrations increased with time during the October study, the ratio OD 663/OD 665a was relatively unchanged and ranged from 1.06 to 1.22. Since the value of the ratio OD 663/OD 665a is expected to range from 1.0 for cells containing degraded chlorophyll to 1.7 for algal cells devoid of phaeopigment, the low values observed in October 1980 indicate that algal populations were in a relatively "poor" physiological state.

47. The trend in the OD 663/OD 665a ratio during the July 1981 study suggests a time- and depth-related decline in the physiological state of algal cells. Although initially high, the OD 663/OD 665a ratio decreased rapidly in the region of the plunge point as algal cells were transported to greater, more light-limited depths.

Phosphorus

48. Although differing in initial concentrations, similar patterns of change in total, total soluble, and particulate phosphorus were observed between studies (Figure 21). In general, concentrations decreased through time.

49. Since flows were similar, the higher initial total phosphorus concentration during the July 1981 study (a large percentage of which was in a soluble form) reflects a twofold higher phosphorus loading rate during this period. The fact that soluble, but not particulate, phosphorus concentration declined rapidly as inflowing waters progressed through the uppermost reach of the study area suggests that algal uptake and settling and/or association with settling particulates may represent a major means by which phosphorus is removed from the water column. High chlorophyll concentrations and decreasing suspended solid concentrations observed in this area support this contention.

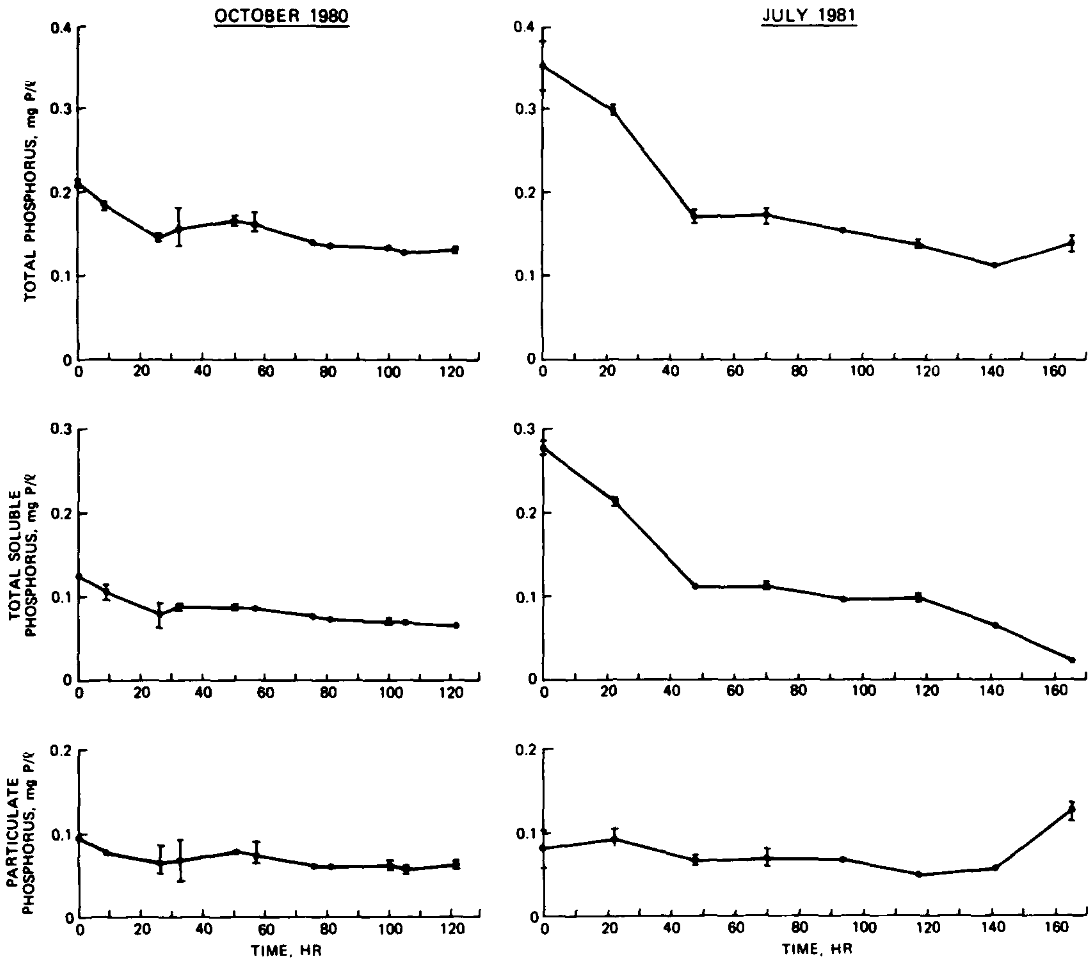

Figure 21. Changes in total phosphorus (upper), total soluble phosphorus (middle), and particulate phosphorus (lower)

Nitrogen

50. Total and total organic nitrogen concentrations during both studies, and ammonium and nitrate concentrations during the October 1980 study, were relatively unchanged through time (Figures 22 and 23, respectively). Ammonium and nitrate concentrations in July, however, displayed opposing trends. Following an initial rapid decline during the time from initial sampling until arrival of the water parcel at the plunge point, nitrate concentration exhibited a gradual decrease. Ammonium concentration increased proportionately during this same period. These changes corresponded with the rapid decline in dissolved oxygen.

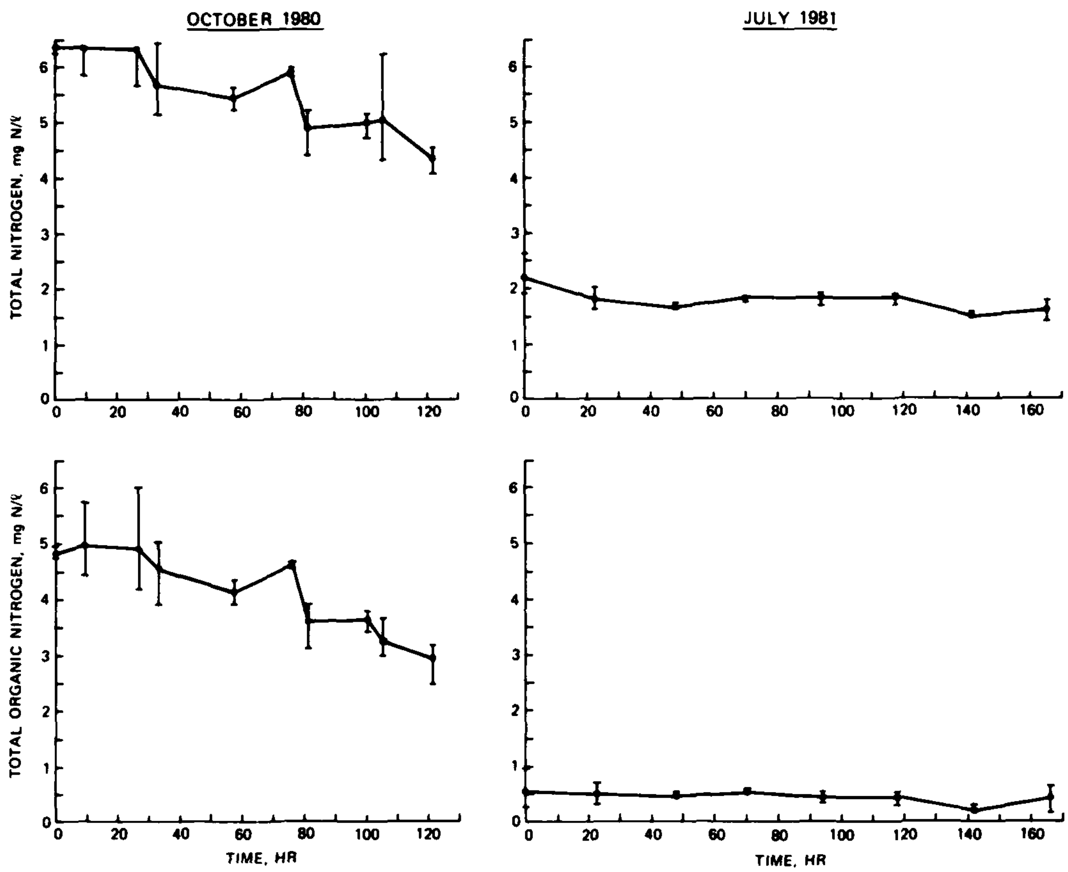

Figure 22. Changes in total nitrogen (upper) and total organic nitrogen (lower)

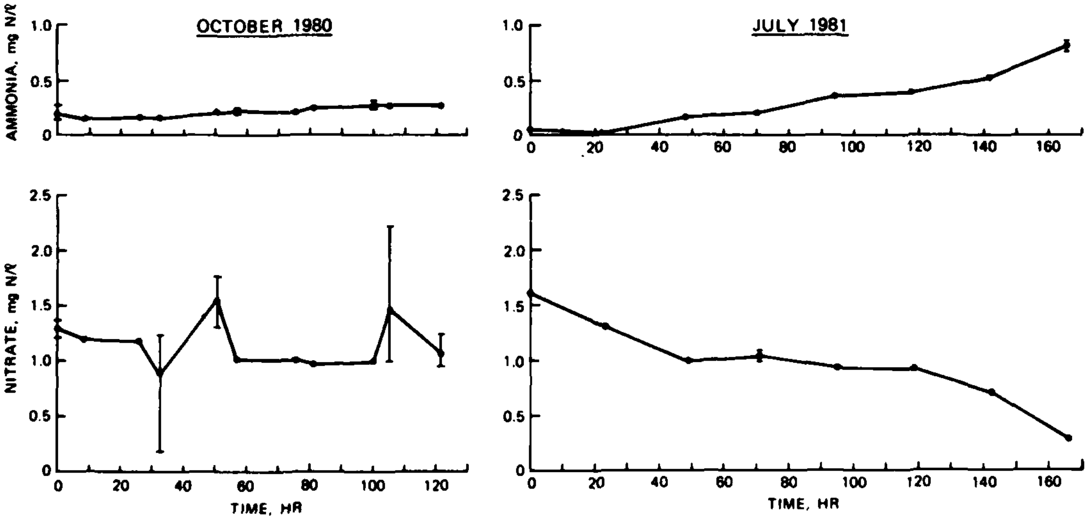

Figure 23. Changes in ammonia nitrogen (upper) and nitrate nitrogen (lower)

Carbon

51. Concentrations of total organic carbon and dissolved organic carbon, which were highly variable between sample replicates, exhibited no clear trend of change with time and were similar during each study (Figure 24). Although not measured during the October 1980 study, dissolved organic carbon represented a large percentage of total organic carbon during the July 1981 study.

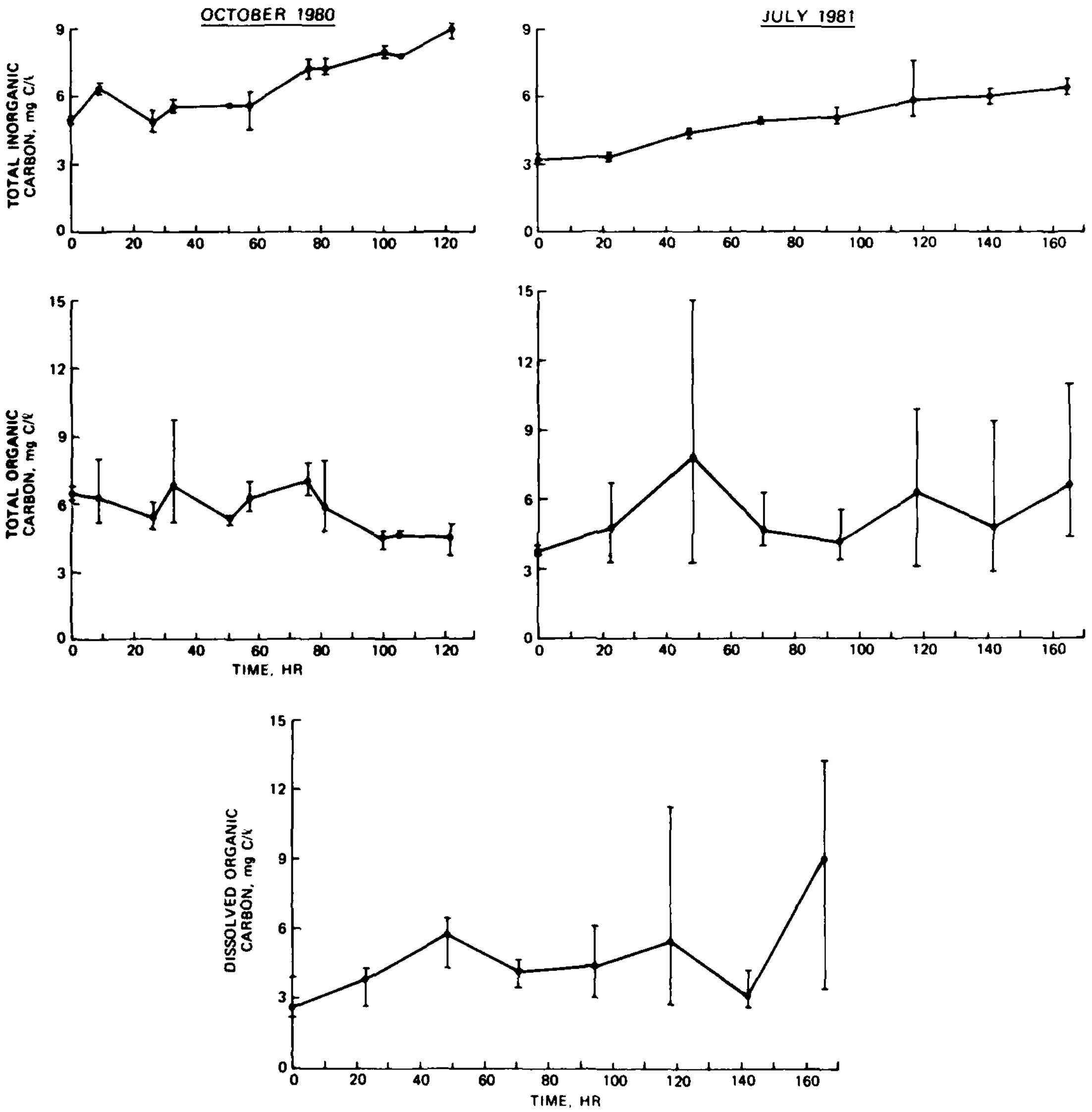

Figure 24. Changes in total inorganic carbon (upper), total organic carbon (middle), and dissolved organic carbon (lower)

52. Time-related changes were apparent for inorganic carbon concentration during both studies. While differing initially, concentrations of inorganic carbon increased approximately twofold during each study period.

Iron and manganese

53. While dissolved iron represented a significantly larger percentage of the total iron concentration during the October 1980 study, total iron (primarily particulate iron) concentrations were higher throughout the July 1981 study (Figure 25). Concentrations of both dissolved and particulate iron were unchanged during the course of the October 1980 study; those in July 1981, while exhibiting high within-sample variability, were also relatively unchanged.

54. Time-dependent increases were observed for total manganese concentration, particularly during the July study (Figure 26). The

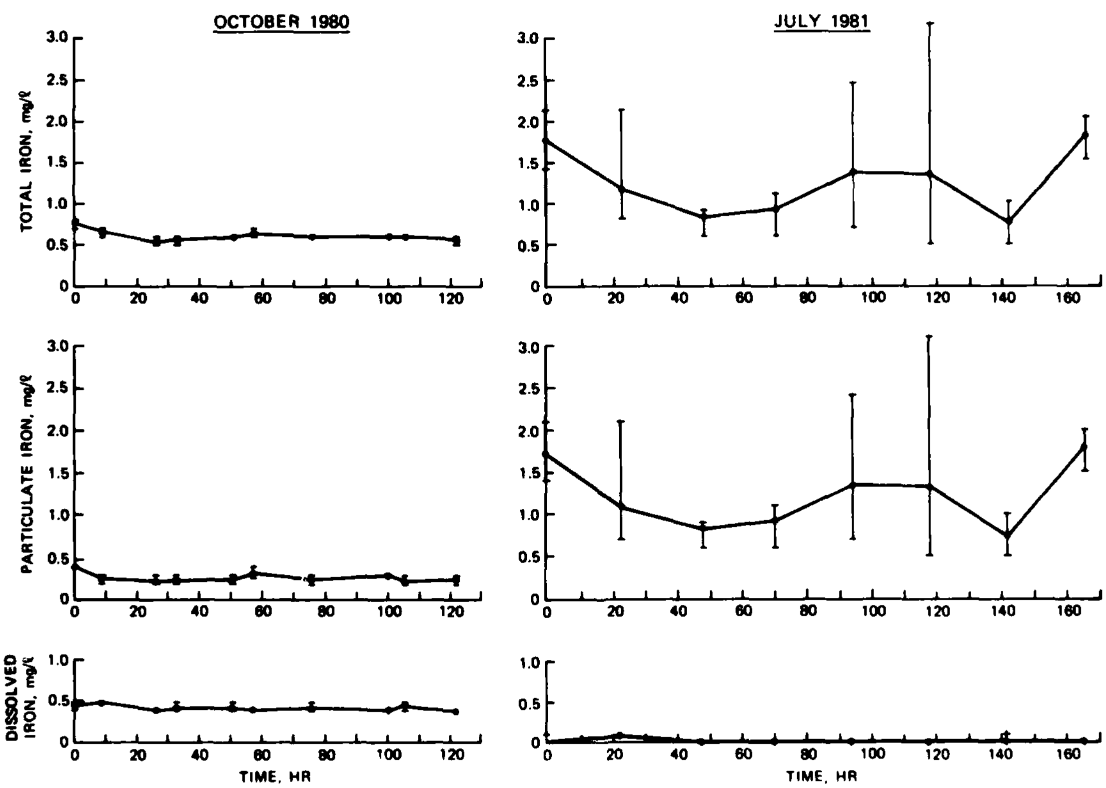

Figure 25. Changes in total iron (upper), particulate iron (middle), and dissolved iron (lower)

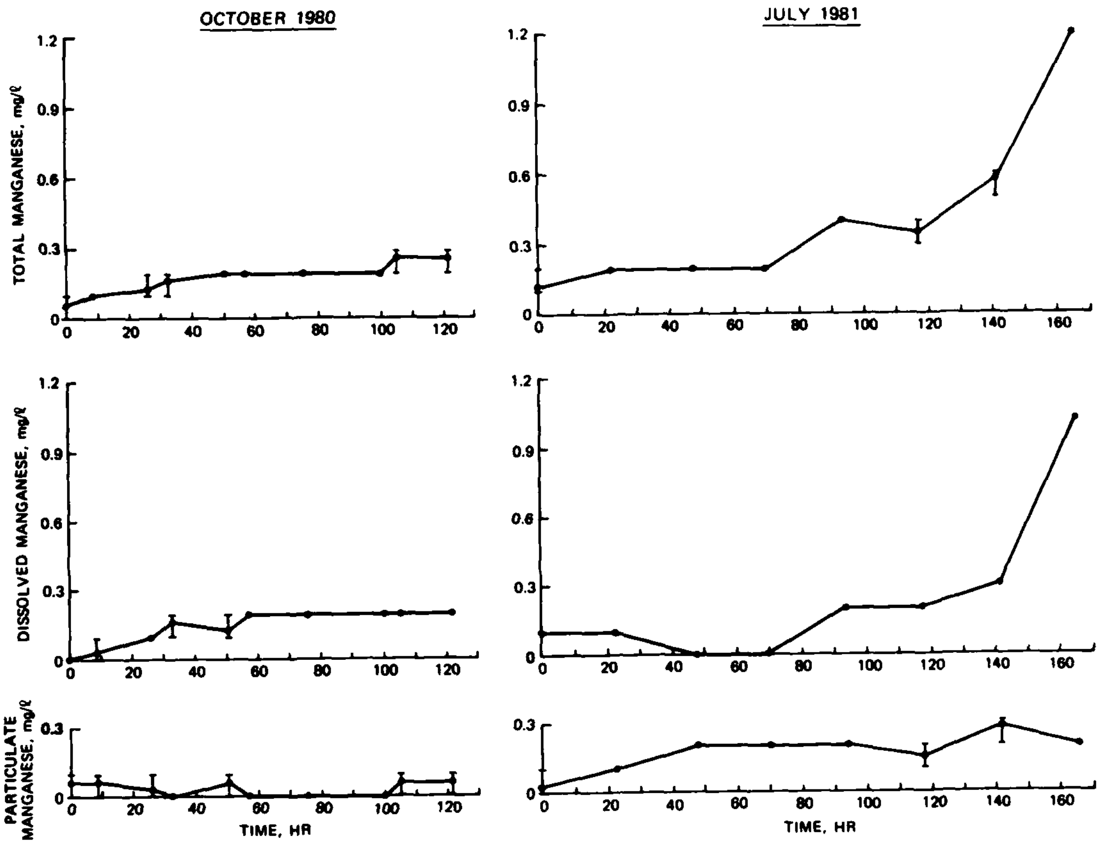

Figure 26. Changes in total manganese (upper), dissolved manganese (middle), and particulate manganese (lower)

abrupt increase in dissolved manganese during July occurred after 72 hr, which corresponds to a location just downstream from the location of the plunge point. Coincident increases in particulate manganese did not occur.

PART V: DISCUSSION

55. Gradients or patterns in water quality from headwater to dam represent the cumulative effects of processes acting to modify the quality of inflowing river water. Under steady-state conditions (i.e., constant flow and inflow water quality), instantaneous observation of differences in water quality along the length of the reservoir provides a means for deducing the nature and extent of these processes. However, under nonsteady-state conditions (i.e. changing flow and inflow water quality), such an evaluation is difficult. Since, in this study, the water quality of each parcel of water along the length of the lake was initially different, patterns in lake water quality observed at any one point in time reflect a time history of changing inflow water quality. If river inputs progress through the reservoir as a density flow, inferences become more tenuous.

56. The use of tracer dyes, such as Rhodamine WT, serves to eliminate the confounding effects of a changing inflow history by allowing the same parcel of inflow water to be repeatedly sampled. Problems associated with the occurrence of density currents are also reduced. Critical to the success of this investigative approach is the assumption of similarity of behavior between dye and inflowing water. Failure of the dye to mix and disperse in a manner similar to the "traced" parcel of water and/or methodological errors could result in erroneous conclusions. Care taken to ensure adequate dilution of dye prior to injection and observations of dye distribution relative to vertical differences in variables measured in situ during these studies provide the only evidence for adherence to this assumption.

57. During the October 1980 study, relatively uniform distributions of dissolved oxygen, temperature, and specific conductance along the study reach, and vertical profiles of dye, indicated plug-flow conditions. This was also indicated by the correspondence of plug-flow calculations of dye location at each sample time and observed location; that is, changes in velocity of the inflowing river water during the October study reflected longitudinal changes in lake cross-sectional area.

58. Inflow regime during the July 1981 study differed markedly from that during the October 1980 study and was related to the thermal structure of the lake. Vertical temperature differences in West Point Lake during summer generally range from 2 to 6° C near the dam, and weak stratification is maintained from April to September (Davies et al. 1979; Georgia Department of Natural Resources 1976). The thermocline is relatively broad and ranges in depth from approximately 5 m to within a few metres of the bottom. During the July 1981 study, the density of inflow water was apparently greater than that of surface waters. Under these conditions, river water will displace lake water until buoyancy forces exceed advective forces (Ford and Johnson 1983). Riverine flows below this point (i.e. the plunge point) will sink beneath less dense layers of lake water and progress downstream confined to intermediate depths of similar density. Such was the case during the July study. Flow velocity in the extreme upstream portion of the study area was relatively high but decreased to near zero in the vicinity of the plunge point. This pooling or stalling of water at the plunge point, which has been demonstrated for other reservoirs (e.g. Ford, Johnson, and Monismith 1980), results in mixing (Ford and Johnson 1983). Beyond the plunge point, flow velocity increases as river water separates from the bottom and is confined to a relatively narrow intrusion zone. Mixing or entrainment of surface and/or bottom waters with the riverine layer at and beyond the plunge point would be restricted by density differences in strongly stratified reservoirs or lakes. However, the weak thermal stratification in West Point Lake suggests a greater potential for entrainment. While entrainment cannot be quantified by these data, changes in chemical composition of the riverine layer (discussed below) provide indirect evidence of the entrainment of bottom waters. Vertical profiles of relative dye concentration, which were skewed with depth, also indicate the mixing of riverine water with epilimnetic water.

59. Inflow characteristics, in addition to their direct effect on the transport and distribution of solutes and suspended material, indirectly influenced inflow water quality and thus, the potential impact of material loads to the lake. Most obvious was the effect of a density

current on dissolved oxygen concentrations of interflowing river water during the July 1981 study. River water was high in organic concentrations at the initiation of the study and, although vertical mixing and photosynthetic activity maintained oxygen concentrations near saturation in upstream areas of the lake, dissolved oxygen declined rapidly downstream from the plunge point. The rapid depletion rate (1.56 g/m^3/day) and the attainment of anaerobic conditions over a period of only 5 days indicated the presence of a large pool of labile organic material and an active microbial community.

60. While metalimnetic dissolved oxygen minima in lakes and reservoirs are often related to the accumulation of settling algal cells near the thermocline and subsequent microbial activity (e.g. Gordon and Skelton 1977), oxygen depletion in the headwater area of West Point Lake appears most related to allochthonous organic inputs and the effects of inflow mixing processes. The confinement of river water containing high concentrations of oxidizable organic matter to subsurface layers in this highly turbid lake reduces photosynthetic activity and restricts reaeration. Subsequent microbial activity leads to a rapid decline in dissolved oxygen in the interflowing riverine layer. Allochthonous particulate material deposited on sediments and into the water column immediately below the thermocline would also accelerate oxygen depletion in the shallow upstream portion of the lake. Such an occurrence may account for the frequent observation that hypolimnetic oxygen deficits are greatest in reservoir headwater areas and that oxygen depletion progresses seasonally from headwater to dam (e.g. Kennedy et al. 1983; Mullan, Morais, and Applegate 1970; Nix 1981; Hannan and Cole 1983).

61. Observed declines in suspended solid concentration and median particle size in upstream areas were expected since flow velocity and, thus, carrying capacity for suspended solids decline below the Chattahoochee River inflow as channel depth and width increase. Changes in median particle size, which were more pronounced than those for suspended solids, reflect the loss of larger particulates at the extreme upstream end of the lake. This is in general agreement with the results of a sediment survey which indicated this area of the lake as a site for

the accumulation of coarser sediments (Gunkel et al. 1983).

62. The presence of and eventual decline in the concentration of influent particulate material are of potentially great consequence for processes occurring in the lake and for determining the ultimate impact of allochthonous loads. In addition to the effects on light availability and the establishment of longitudinal gradients in chlorophyll standing crop (Kennedy, Thornton, and Gunkel 1982), suspended solids may also influence the quantity and form of nutrients along the lake's length. Green, Logan, and Smeck (1978) determined that fluvial sediments borne by the Maumee River were higher in phosphorus than watershed soils due to the selective erosion of fine soil particles and/or adsorption of phosphorus during fluvial transport. Schreiber and Rausch (1979) reported the relative enrichment of suspended sediment with phosphorus (i.e. increased phosphorus per unit weight of suspended sediment) from inflow to outflow of a flood detention reservoir due to the preferential deposition of larger, less phosphorus-enriched particulates. Particulate deposition also accounts for major losses in nutrients, organic matter, and metals in the headwater areas of DeGray Lake (Kennedy et al. 1983; James and Kennedy 1983). The desorption and adsorption of chemical constituents may also factor in determining the impact of suspended sediments on the water quality of receiving waters by adding or removing dissolved material in the water column (e.g. Bahnick et al. 1978; Gloss, Mayer, and Kidd 1980). Once deposited in the headwater areas of West Point and other river-fed lakes and reservoirs, these sediments could continue to influence water column conditions through sediment/water exchanges (e.g. To and Randall 1975; Kennedy et al. 1983).

63. Changes in the concentration of dissolved inorganic nitrogen during the July 1981 study reflect the influence of the density current and resultant reduced oxygen concentrations. The reduction in nitrate concentration during the first 48 hr (i.e. above the plunge point) is attributable to uptake by a large, physiologically active phytoplankton community in the upper reaches of the study area. The steady increase (0.14 mg N/day) in ammonia nitrogen concentration, which occurred coincident with the decline in dissolved oxygen concentration, is related to

the reduction in bacterial nitrification and resultant accumulation of ammonia, and to bacterial degradation of organic material. Such changes did not occur during the October 1980 study due to differing flow regime and oxygen conditions.

64. Disparity in the patterns of occurrence of iron and manganese downstream from the plunge point during the July 1981 study suggests the entrainment of hypolimnetic water by the interflowing riverine layer. While the concentrations of particulate iron and manganese were relatively unchanged during both study periods, dissolved manganese concentration increased markedly in July at stations downstream from the plunge point. Similar increases in dissolved iron did not occur. Since total manganese concentration increased, the reduction of suspended insoluble manganese would not account for the increase in dissolved manganese. The only available source of additional manganese would be the pool of reduced, soluble manganese present in hypolimnetic waters below the riverine layer.

65. While data for manganese concentrations at these depths in July 1981 are lacking, data collected at five stations along the length of West Point Lake during 1979 provide indirect support of this suggestion (Figure 27). During the period 11 June to 20 August 1979, dissolved oxygen concentrations above sediments were at or near zero at stations from mid-lake to the dam. Concentrations of total iron and total manganese immediately above sediments were progressively higher with distance downstream. However, between-station differences in dissolved iron and dissolved manganese were apparent. Hypolimnetic dissolved iron increases occurred only at an extreme downstream station, while increases in dissolved manganese occurred farther upstream and coincided with increases in total manganese.

66. These differences in dissolved iron and dissolved manganese distribution were apparently related to differences in thermodynamic response under near-anoxic conditions. Since manganese is solubilized at a relatively higher redox potential and oxidized at a slower rate than iron (Wetzel 1975), higher, more persistent manganese concentrations would be expected in shallow hypolimnetic areas near the location of the

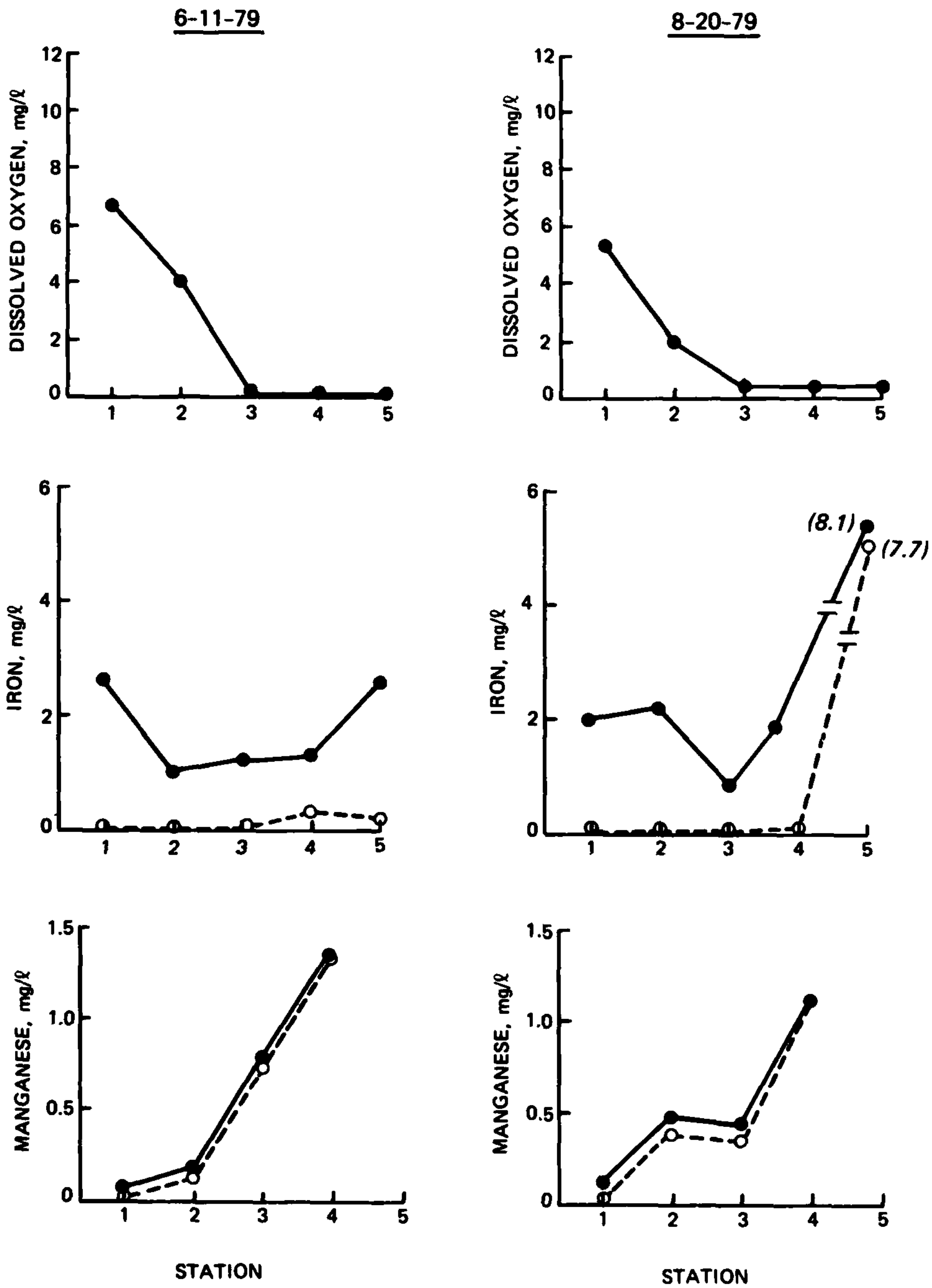

Figure 27. Longitudinal distribution of dissolved oxygen (upper) and dissolved (o---o) and total (●—●) iron (middle) and manganese (lower) approximately 1 m above West Point Lake sediments on 11 June and 20 August 1979. Stations were located approximately uniformly from headwater station 1) to the dam (station 5)

plunge point. If conditions in July 1981 were similar to those in 1979, the entrainment of hypolimnetic waters high in dissolved manganese would have resulted in the observed increase in manganese in the riverine layer. As mentioned above, the weak thermal stratification observed during the July study suggests the potential for entrainment.

67. Similar occurrences have been reported for DeGray Lake (Nix 1981). The entrance of cooler, more dense Caddo River water resulted in an interflow and a metalimnetic oxygen minima, which was due, in part, to the oxidation of reduced manganese entrained by the riverine layer. The importance of mixing and transport processes in this lake was further suggested from sediment trap studies (James and Kennedy 1983; Gunkel, Kennedy, and James 1982) since the seasonal migrations of the thermocline and the riverine inflows result in a redistribution of hypolimnetic manganese entrained by the riverine layer.

68. Both studies at West Point Lake were conducted during periods of relatively stable inflow conditions. During the July study, this resulted in a stationary plunge point. However, the location of the plunge point during previous studies (Kennedy, Thornton, and Gunkel 1982) has been observed to change, often on a daily basis, in response to changes in flow. Under these conditions, the above-mentioned entrainment of hypolimnetic water would be potentially more significant. As flows increase, the position of the plunge point and the point of separation of the riverine layer from bottom sediments would progress farther into the lake. This, in turn, would result in annexation by the riverine layer of bottom water from the shallow, upstream end of the hypolimnion. If these waters are high in chemical constituent concentrations, this would result in an immediate effect on concentrations in the riverine layer. Thus, variation in flow would act to "pump" hypolimnetic water from the upstream portion of the hypolimnion to downstream metalimnetic areas.

PART VI: CONCLUSIONS

69. Processes occurring within West Point Lake headwater areas impact the quality of inflowing river water and thus, in turn, influence the ultimate impact of material loads on the water quality of the lake. Sedimentation of influent particulates directly influences light regime, leading to reduced phytoplankton production, and may effect a change in nutrient, metal, and organic concentrations.

70. Water quality conditions in the lake's headwater area are further influenced by flow regime. Reduced reaeration and reduced light availability as inflowing water sinks below surface waters lead to reduced photosynthetic activity and depletion of dissolved oxygen. Coincident changes in chemical composition reflect the combined effects of sedimentary losses, entrainment of lake water, and metabolic processes occurring in the water column.

71. These results raise questions concerning the efficacy of simplifying assumptions commonly applied in the interpretation of lake water quality data. The fact that losses of sediment, nutrients, and other influent materials in the headwater area lead to the establishment of longitudinal water quality gradients suggests that the assumption that influent materials are completely and instantaneously mixed throughout the lake may not be completely appropriate for long, narrow lakes with a single, large tributary.

72. The occurrence of density flows (i.e. interflow, underflow) would suggest that epilimnetic waters are isolated from the impacts of material loads. However, results here indicate the introduction of dye (and thus, riverine water) into the epilimnion. The entrainment of hypolimnetic water by the riverine layer was also demonstrated. Thus, vertical movements of water and material are possible in the dynamic headwater area of the lake. The implications of this are great since the hypolimnion and the riverine layer are potential sources for replenishing dwindling nutrient supplies in surface waters.

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Table 1

Selected Limnological Characteristics of West Point Lake

Average pool elevation	193.6 m msl
Surface area	104.8 km^2
Volume	$745.7 \times 10^6 m^3$
Maximum depth	31 m
Mean depth	7.1 m
Reservoir length	53 km
Shoreline length	844.7 km
Drainage area	5535 km^2
Residence time	0.17 year
Total alkalinity	15.2 mg $CaCO_3/\ell$
Total organic carbon	4.6 mg C/ℓ
Total phosphorus	0.04 mg P/ℓ
Total nitrogen	0.78 mg N/ℓ
Total manganese	0.22 mg Mn/ℓ
Total iron	0.71 mg Fe/ℓ

Table 2

Sampling and Dye Injection Schedule

Date	Station No.	Sample Depth, m	Sample Time	Injection Depth, m	Injection Time	Quantity of Dye Injected, ℓ
			October 1980			
10-26	1	0	0850	0	0925	15.1
10-26	2	3.0	1650	1.5*	1705	34.0
10-27	3	2.0	1100	2.0	1115	11.4
10-27	4	3.0	1700	3.0	1720	22.7
10-28	5	4.0	1115	4.0	1135	7.6
10-28	6	8.0	1645	4.0**	1745	24.6
10-29	7	5.0	1045	5.0	1105	15.1
10-29	8	6.0	1615	6.0	1715	26.5
10-30	9	6.0	1135	--	--	0
10-30	10	6.0	1620	6.0	1705	26.5
10-31	11	6.0	0905	--	--	--
			July 1981			
7-22	1	0	1425	0	1441	37.9
7-23	2	0	1250	0	1330	41.6
7-24	3	3.0	1405	3.0	1442	41.6
7-25	4	4.0	1230	4.0	1324	41.6
7-26	5	6.0	1220	6.0	1240	41.6
7-27	6	6.0	1200	6.0	1220	41.6
7-28	7	7.0	1205	7.0	--	45.4
7-29	8	8.0	1200	--	--	--

* Since dye was uniformly distributed vertically, reinjection of dye was performed at approximately mid-depth.

** Dye injection depth adjusted for possible methodological error. See explanation in paragraph 30.

Table 3

Analytical Methods

Variable	Sample Preparation	Sample Preservation	Analytical Method	Reference
Temperature	In situ	In situ	Hydrolab Model 8000	--
Dissolved oxygen	In situ	In situ	Hydrolab Model 8000	--
Specific conductance	In situ	In situ	Hydrolab Model 8000	--
pH	In situ	In situ	Hydrolab Model 8000	--
Total alkalinity	None	Field analysis	Potentiometric titration (pH 4.5) with 0.02 N H_2SO_4	U. S. Environmental Protection Agency (U. S. EPA) (1974)
Suspended solids	Filtration (0.45 μ)	Dark; 4° C	Change in weight of a tared, 0.45-μ membrane filter dried at 105° C	APHA (1980)
Turbidity	None	Dark; 4° C	Nephelometry using a Hach Portalab Turbidimeter (Hach Chemical Co., Ames, Iowa)	Manufacturer
Particle size	None	6% formalin (16 ml/ℓ); calgon (8 ml/ℓ)	Electrical potential using Counter Model TAII Particle Size Counter (Coulter Electronics Inc., Hialeah, Fla.)	Manufacturer
Nitrate nitrogen	Filtration (0.45 μ)	$HgCl_2$ (40 mg Hg/ℓ)	Brucine-sulfanilic acid	U. S. Department of the Interior (1979)
Ammonia nitrogen	Filtration (0.45 μ)	$HgCl_2$ (40 mg Hg/ℓ)	Distillation-nesslerization	U. S. Department of the Interior (1979)
Total Kjeldahl nitrogen*	None	H_2SO_4 (8 ml/ℓ)	Kjeldahl digestion and selective-ion probe	APHA (1980)

(Continued)

* October 1980 study only.

Table 3 (Concluded)

Variable	Sample Preparation	Sample Preservation	Analytical Method	Reference
Total Kjeldahl nitrogen*	None	$HgCl_2$ (40 mg Hg/ℓ)	Kjeldahl digestion, distillation, and indophenol colorimetric reaction	U. S. Department of the Interior (1979)
Total phosphorus	None	None; storage in digestion vessel	Acid-persulfate digestion; ascorbic acid-molybdate colorimetric reaction	Jeffries, Dieken, and Jones (1979)
Total soluble phosphorus	Filtration (0.45 μ)	None; storage in digestion vessel	Acid-persulfate digestion; ascorbid acid-molybdate colorimetric reaction	Jeffries, Dieken, and Jones (1979)
Total organic carbon	None	H_2SO_4 (pH $\leq$ 2); amber glass storage	Persulfate oxidation; infrared analysis	U. S. EPA (1974)
Dissolved organic carbon*	Filtration (precombusted glass fiber)	H_2SO_4 (pH $\leq$ 2); amber glass storage	Persulfate oxidation; infrared analysis	U. S. EPA (1974)
Soluble iron and manganese	Filtration (0.45 μ)	HNO_3 (pH $\leq$ 2)	Atomic absorption	APHA (1980)
Total iron and manganese	None	HNO_3 (pH $\leq$ 2)	Atomic absorption	APHA (1980)
Chlorophyll a	Filtration (glass fiber)	4° C, dark; freezing	Tri-chromatic spectrophotometry	Strickland and Parsons (1968)

* July 1981 study only.

Table 4

Comparison of Physicochemical Characteristics of the Chattahoochee River (at Franklin, Ga.) at the Initiation of Each Study and During the Period October 1979 through September 1981

Variable	Initiation 26 Oct 1980	Initiation 22 Jul 1981	Oct 1979 through Sep 1981*
Flow, m^3/sec**	45	52	111 (37 - 725)
Temperature, °C	14.9	31.2	18.8 (8.0 - 28.5)
Dissolved oxygen, mg/ℓ	8.9	8.0	7.7 (4.9 - 9.7)
Specific conductance, µmhos/cm	84	85	78 (40 - 98)
pH	6.6	6.9	6.9 (6.5 - 7.2)
Turbidity, NTU's†	15.7	10.5	26 (6 - 68)
Total alkalinity, mg $CaCO_3$/ℓ	12.5	11.8	16 (10 - 20)
Suspended solids, mg/ℓ	18.1	26.6	49 (8 - 129)
Median particle diameter, µ	25.0	9.6	--
Total inorganic carbon, mg/ℓ	--	3.2	--
Total organic carbon, mg/ℓ	6.5	3.8	2.9 (<1.0 - 8.0)
Dissolved organic carbon, mg/ℓ	--	2.7	--
Total phosphorus, mg/ℓ	0.30	0.35	0.27 (0.03 - 0.55)
Total soluble phosphorus, mg/ℓ	0.13	0.27	--
Total Kjeldahl nitrogen, mg/ℓ	0.53	0.58	--
Nitrate/nitrite nitrogen, mg/ℓ	0.67	1.60	0.97 (0.32 - 1.5)
Ammonium nitrogen, mg/ℓ	0.19	0.04	0.23 (0.04 - 0.74)
Particulate iron, mg/ℓ	0.4	1.7	--
Dissolved iron, mg/ℓ	0.4	<0.1	0.17 (0.06 - 0.27)††
Particulate manganese, mg/ℓ	<0.1	<0.1	--
Dissolved manganese, mg/ℓ	<0.1	0.1	0.03 (0.02 - 0.04)††

* Mean (n = 22) and range of values observed approximately monthly (from USGS 1981, 1982).
** Recorded at Whitesburg, Ga., 39.1 km upstream from Franklin, Ga.
† NTU = Nephelometric turbidity units.
†† Observed at Whitesburg, Ga., and based on less frequent sampling (n = 4).

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